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EARLY COMPONENTS OF THE SOCIAL BRAIN: UNDERSTANDING COMMUNICATION THROUGH PERCEPTUAL CONSTRAINTS

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RIASSUNTO

L’obiettivo di questo lavoro è di investigare, durante il primo anno di vita ed in particolare in bambini di 0, 6 e 12 mesi, lo sviluppo delle aree cerebrali che controllano le abilità sociali che intervengono nella comunicazione tra gli individui e che costituiscono le abilità indispensabili per un adeguato adattamento dell’uomo nel proprio ambiente sociale. Brothers nel 1990 propose di chiamare queste regioni cerebrali, dedicate alla cognizione sociale, “Social Brain”. È noto in letteratura che lo sviluppo del “Social Brain” include lo sviluppo di abilità che sono fondamentali per comunicare con gli altri e manipolare informazioni sociali rilevanti per la vita quotidiana. Molti studi si sono focalizzati sull’investigazione delle strutture cerebrali che giocano un ruolo fondamentale nel guidare i comportamenti sociali poichè gli esseri umani sono caratterizzati dalla capacità di estrarre ed interpretare da semplici indizi (come per esempio la direzione dello sguardo) complesse situazioni sociali. Tra i numerosi lavori che hanno investigato lo sviluppo del “Social Brain” durante il corso della vita (nei neonati, nei bambini e negli adulti), un aspetto dello sviluppo della cognizione sociale che ha trovato una forte rilevanza è la percezione e l’elaborazione degli altri come agenti intenzionali. Alcuni ricercatori suggeriscono che le abilità dei bambini di riconoscere gli scopi delle azioni si sviluppano grazie alla diretta esperienza con gli agenti umani e solo successivamente, nel corso della vita, si estende gradualmente agli altri tipi di agenti (i.e. oggetti inanimati). Secondo questa prospettiva i bambini possono attribuire degli scopi ad agenti umani ma non agli altri oggetti inanimati (Woodward, 1998). Altri ricercatori propongono, invece, che l’attribuzione di intenzionalità agli agenti sia legata alla presenza di determinate caratteristiche fisiche (come l’autopropulsione descritta come la capacità di muoversi da soli, la direzione del

movimento, la variazione equifinale del movimento intesa come la capacità di raggiungere lo stesso obiettivo con modalità e percorsi differenti, e l'efficacia dell'azione), per questo propongono che i bambini piccoli possano attribuire gli scopi delle azioni sia agli agenti animati che agli agenti inanimati (Bíró e Leslie 2007; Bíró, Csibra e Gergely, 2007). Oltre all'aspetto umano o inanimato dell'agente, anche il ruolo del movimento biologico/sociale versus non biologico/meccanico rappresenta un altro indizio utilizzato per identificare entità e comportamenti come diretti ad uno scopo (Lloyd, Blasi, Volein, Everdell, Elwell and Johnson, 2009). In particolare, è possibile ipotizzare che quando il movimento è biologico (come il movimento di un essere umano) oppure meccanico (non fluido, non armonico, rigido), la sua associazione con differenti caratteristiche fisiche possa modificare l'interpretazione dell'azione diretta ad uno scopo. Per indagare il ruolo del movimento biologico e non biologico nella comprensione dell'intenzionalità di un azione in bambini di 6 mesi ho eseguito cinque esperimenti. I risultati raggiunti dimostrano che la comprensione delle azioni diretta ad uno scopo dipende dalle differenti caratteristiche fisiche dell'agente e dalla presenza o meno di una componente comunicativa. In particolare la capacità degli agenti di muoversi in modo autonomo sembra essere fondamentale per identificare le azioni dirette ad uno scopo. La presenza di questa capacità viene proposta da alcuni studiosi come una precondizione per la costruzione di un riconoscimento di azione finalizzata: solo quando il movimento di un oggetto viene percepito autonomo, il bambino potrà considerare altri indizi rilevanti per identificare lo scopo dell'azione (Premack, 1990; Baron-Cohen, 1994). In accordo con questa prospettiva precedenti evidenze dimostrano che i bambini possono comprendere un azione intenzionale non solo quando l'agente è biologico e quindi umano, come per esempio una mano, ma anche quando l'agente è un oggetto inanimato purché sembri muoversi in modo indipendente (Luo e Baillargeon, 2005). Altre evidenze, però, dimostrano che, almeno in bambini di 12 mesi, la possibilità che un agente si muova in modo autonomo non è necessaria al fine di attribuire uno scopo all'azione e la sua assenza non necessariamente inibisce l'interpretazione dei comportamenti come diretti ad uno scopo (Bíró, Csibra e Gergely, 2007). I risultati ottenuti in un secondo studio da me svolto tuttavia dimostrano che quando il movimento dell'agente non è autonomo è assolutamente necessaria la presenza della componente comunicativa nell'agente per permettere al bambino di comprendere l'intenzionalità dell'azione. Questi risultati sono supportati anche dall'ultimo studio di neuro immagine (nel quale viene utilizzata una tecnica di neuro immagine non invasiva: NIRS) che dimostra che le regioni cerebrali del solco temporale superiore (regioni incluse nella aree del facenti parte del "Social Brain") sono coinvolte nell'elaborazione di stimoli dinamici sociali fin dai primi mesi di vita. In conclusione questi studi sembrano suggerire che alla base dello sviluppo sociale vi sia una forte interazione tra l'esperienza e la naturale predisposizione delle strutture cerebrali. Sembra che lo sviluppo delle funzioni cerebrali nell'uomo non sia dovuto ad una passiva sequenza maturazionale, ma sia dovuto ad un processo attivo mediato dall'esperienza e guidato da predisposizioni innate come suggerito dall'ipotesi neuro costruttivista (Karmiloff-Smith, 2009).

ABSTRACT

The focus of this research is the investigation, during the first year of life and in particular in 6 and 12 months old infants, of the development of the brain structures which are implicated in the social abilities. These abilities are fundamental for the people's communication and they are essential for an appropriate human's adaptation in its own social environment. Brothers in 1990 proposed to call this set of brain regions, which are dedicated to the social cognition as the "social brain". It is well known in the literature that the development of the "social brain" includes the development of the abilities which are fundamental to communicate each other and to manipulate socially relevant information. Many studies have focus on several brain structures that play a key role in guiding social since the human being is characterized by the capacity to extract and interpret from simple cues (i.e. eye gaze) complex social state. There are a lot of studies that have investigated the development of the social brain during the life course (in newborn, infants and adults) and in these studies one of the most relevant aspects of the social cognition development studied/ which is studied is the perception of others as intentional agents. Some researchers have suggested that infants' ability to reason about goals is developed as a result of direct experience with human agents and is then gradually extended to other agents (e.g. inanimate objects). This view predicts that young infants should attribute goals to humans, but not to other inanimate objects (Woodward 1998). Other researchers have proposed that goal attribution is rooted in a specialized system of reasoning which is activated whenever infants encounter entities with appropriate features (e.g., self-propulsion, equifinal variations, action-effect) and that young infants should attribute goals to both human and nonhuman agents (Bíró and Leslie 2007; Bíró, Csibra and Gergely, 2007). In addition to

the humans or inanimate aspect’s agent, the role of the biological/social vs non-biological/mechanical motion is a further cue in order to identifying entities and behaviours as goal-directed (Lloyd, Blasi, Volein, Everdell, Elwell and Johnson, 2009). In particular, it is possible to suppose that since a motion could be biological (like the motion of a human be) or mechanical (not fluid, not harmonic, rigid), its association with different features could have modified the interpretation of the goal-directed actions. To investigate the role of the biological and non-biological movement in the comprehension of the intentionality of an action in 6 months old infants it was run five experiments. The results showed that the comprehension of goal-direct actions depends on different agents’ features and on communicative cues can modify the interpretation of goal directed actions. In particular the self-propelledness seem to be a fundamental characteristics for identifying goal-directed actions. The presence of self-propelledness was proposed by some (Premack, 1990; Baron-Cohen, 1994) as a precondition for setting up a goal-directed interpretation: only when an object’s motion is self-propelled infants will consider other cues relevant for identifying the goal of the action. According to this view, previous evidences claimed that infants can understand an intentional action not only when the agent is a biological actor, like an hand, but also when the agent is an inanimate object and seems to move in an independent way (Luo and Baillargeon, 2005). Others however, demonstrated that for 12-month old infants self-propulsion is not a necessary prerequisite for goal attribution and its absence does not necessarily inhibit the interpretation of behaviours in terms of goals (Bíró, Csibra and Gergely, 2007). With the second study we suggest the hypothesis that when the self-propelldness is not presence is absolutely necessary the presence of a communicative characteristic in the agent to permit infants to understand the intentionality of the action. This findings is supported also by the third neuro-imaging studies (NIRS study) showing that brain regions in the Superior Temporal Sulcus (a region included in the regions of the “social brain”) are involved in social interaction in response of dynamic social stimuli from the first months of life. In conclusion our findings seem to suggest that an interaction between the experience and the natural predispositions of the brain structural is at the basis of the social development. It seems that the human functional brain development is not just a passive maturational sequence, but is an activity processes mediate by experience and guides by initial predispositions, as neurocostruttivism view propos (Karmiloff-Smith, 2009).

CHAPTER 1

THE NEUROCOSTRUCTIVISM APPROCH

The present thesis takes a neurocostructivism perspective. In this view ontogenetic development is considered to be the constructive process by which genes interact with their environment at various levels to construct complex organic structures such as the brain and the cognitive processes it supports. Cognitive development is explained as emerging from the experience-dependent development of neural structures supporting mental representations. Neural development occurs in the context of multiple interacting constraints acting on different levels, from the individual cell to the external environment of the developing child (Westermann, Maraschal, Johnson, Sirois, Spratling and Thomas, 2007, Karmiloff-Smith, 2009). Moreover this perspective offers an integrated view of development and adult brain processing. The neuro-constructivism originates from a recent debate about the dichotomy between a specific innate mechanism and a general one. A previous trend of thought about ontogenitic development was the constructivism in which the biological structures are seen as an emergent property of complex interactions between genes and environment. The most famous proponent of this view with regard to the cognitive development was the psychologist Jaen Piaget (1954). The essence of the Piaget’s position, known as *epigenetic constructivism,* is that the relationship between the initial state and the final product can only be understood by considering the progressive construction of information. This construction is a dynamic process to which multiple factors contribute. In particular the cognitive development is considered as the outcome of a self-organizing system which is structured and shaped by its interaction with the environment. The newborn mind is equipped with domain-general processes, which, with innate reflexes, products the development process and where the environment supplies the rest. So the most important thing is that the baby acts in the environment because the cognitive development is a process based on previous skills and existing structures to form the world knowledge. This constructivism view of development was challenged by the nativism view, according to which the newborn is seen as having domain-specific predispositions allowing him to process specific types of inputs (Spelke, 1990, Baillargeon & Wang, 2002). For the nativism point of view humans are born with the innate capacity to develop information by using cognitive modules. This perspective was deeply influenced by Chomskyan linguistics (1988) and by Fodor's modularity theory (1983). In those approaches the baby is born prepared to process information belonging to different domains of knowledge starting from an innate predisposition. But the term "innate" has rarely been explicitly defined. Indeed, it was disused and even actively banned in many areas of the developmental biology. The main reason for the term having been dropped from use in the fields of biology such as ethology and genetics is because it is simply no longer useful since it has become evident that genes interact with their environment at many levels, including the molecular one (Gottlieb, 1992). There is no aspect of development that can be said to be strictly "genetic", or exclusively a product of information contained within particular genes. If the term "innate" describes a structure that is completely specified by genetic information, it refers to nothing that exists in the natural world. For this reason, in cognitive science the use of the term "innate" persists probably for the need to have a term to describe the interaction between the developing child's intrinsic factors and the features of the external environment.

Even the "mechanism" proposed by Piaget appeared somewhat elusive on closer inspection. Another problem with the constructivism approach was that, despite this emphasis on interaction, it was unclear how to analyse the development without the traditional dichotomy between innate and environmental factors. By taking a neuroscience approach to psychological development, in conjunction with a number of new theoretical approaches, it was possible to flesh out the constructivism approach and to provide new ways to analyse cognitive and brain development giving way to the neo-constructivism approach. According to this approach the nativism and the epigenetic principles are not incompatible because it assumes the existence of some innate specific predisposition which would give the epigenetic process a start in each domain of knowledge (Karmiloff-Smith, 1992). The *probabilistic epigenetic* approach emphasizes the fact that genes activity is regulated by signals from the external and internal environment and it considers the interaction between genes, structural brain changes, behaviour and environment as bidirectional (Gottlieb, 2007). It assumes that the brain has a range of possible development paths and end state. They depend on the particular constraints that occur. The neuropsychological equivalent of the neo-constructivism is the neuro-constructivism that is the framework on which recent researches have investigated the development of the "social brain" and based on which we have conducted our studies described in the present work. Understanding cognitive development requires an understanding of how the neural substrates supporting mental representations are shaped. Neuro-constructivism views the development of the neural system as heavily constrained by multiple interacting factors intrinsic and extrinsic to the developing organism. From this perspective, the cognitive developmental trajectory takes shape in the context of constraints operating on the development of the brain. These constraints span multiple levels of analysis, from genes and individual cell to the physical and social environment of the developing child. In particular neural development, especially in the cerebral cortex, is often dependent on neural activity which can be mediated by experience with the environment. The brain development incorporates organizing and learning mechanisms which are constrained by intrinsic factors, other brain systems (such as subcortical biases) and interactions with the physical (i.e objects, space) and social environment (Johnson,2008).

CHAPTER 2

THE SOCIAL BRAIN

Social cognition in humans guides behaviours which are both automatic or driven by the stimuli and voluntary deliberative and sensitive to context and strategy, allowing people to participate in a variety of processes that modulate behavioural response: memory, decision-making, attention, motivation and emotion which are all prominently recruited when socially relevant stimuli elicit behaviour. In particular social cognition refers to processes that subservice behaviours in response to conspecifics (other individuals of the same species) and also to those higher cognitive processes subserving the extremely diverse and flexible social behaviours that are seen in primates like humans. In fact the human brain is characterized by the unique ability to process stimuli in a social context, extract and interpret from simple cues (i.e. eye gaze) complex social states. In literature many studies have focused on several brain structures that play a key role in guiding human behaviours directed to a social environment and in the discrimination between “objects” and “social relevant objects” like other individuals. These brain structures appear to mediate between perceptual representations of socially relevant stimuli and people’s knowledge. Brothers in 1990 proposed to call this set of brain regions, which are dedicated to the social cognition, “the social brain”. This is the network selectively activated when people are presented with someone or when they need to process information about their conspecifics and it includes the development of the abilities fundamental to communicate with each other and to manipulate socially relevant information. The ability to decode social cues from motion such as eyes, gaze, emotional expression, gestures provides the foundation of social perception and allows us to comprehend intentions, desires, emotions, feelings, and other people's thoughts. The function of the social brain is to enable people to make predictions during social interactions that means to survive in a social complex world.

1. The neural basis of the social brain

One of the major characteristics of the human brain is its social nature. Human adults have areas of the brain specialized in processing and integrating sensory information about the appearance, behaviour and intentions of other humans. In the last decade the notion that there is a 'social brain' in humans specialized in social interactions has received considerable support from brain imaging and, to a lesser extent, from lesion studies. Specific roles for the various components of the social brain are beginning to emerge. Recent data identify a variety of social cognition distinct components. In posterior temporal cortex, the Superior Temporal Sulcus (STS) is associated with perceiving the form of other human bodies and it is involved in interpreting the motions of a human body (Allison, Puce, and McCarty, 2000). Functional magnetic resonance studies investigated the cortical activations in response to the vision of moving eyes, moving mouths or movements of check patterns[1]. The results revealed that moving eyes and mouths activated a bilateral region located in the posterior superior temporal sulcus. The moving check patterns did not appreciably activated the STS or surrounding areas (Puce, Allison, Bentin, Gore & McCarthy, 1998).

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[1] colored checkerboard patterns with checks reversing position in spatially equivalent positions (*white arrows*) to the real eyes and mouth (Puce, Allison, Bentin, Gore & McCarthy, 1998)

This results suggested that the superior temporal region located in the STS was preferentially involved in the perception of gaze direction and mouth movements. The fusiform area “face area” (FFA) is implicated in processing and in recognizing face-stimuli. The amygdala attaches emotional value to faces, enabling us to recognize expressions such as fear and trustworthiness. The medial prefrontal cortex is divided into at least two subregions: the ventral medial prefrontal cortex is implicated in emotional empathy, whereas the dorsal medial prefrontal cortex is implicated in the uniquely human representation of triadic relations between two minds and an object, supporting shared attention and collaborative goals (Adolphs, 1999; Saxe 2006; Frith, 2007). It has been more difficult to assign a role to the medial prefrontal cortex, which is consistently activated when people think about mental states. Probably this region may have a special role in the second-order representations needed for communicative acts when people have to represent someone else's representation of our own mental state. These cognitive processes have been driven to ever higher levels of sophistication by the complexities of social interaction, for this reason the social brain allows us to interact with other people. It is possible to argue that the function of the social brain is to enable human beings to make predictions during social interactions. These predictions need not be conscious and deliberated. Perhaps one the most important attributes of the social brain is that it allows individuals to make predictions about people’s actions on the basis of their mental states. This assumption that behaviour is caused by mental states has been called ‘intentional stance’ (Dennett 1987). This automatic process is used by people to ‘read’ the mental states of others and it is called mentalizing. Our social brain has two problems to solve: first it must read the mental state of the person we are interacting with, second it must make predictions about possible future behaviours on the basis of that mental state.

2. The development of the neural basis of the social brain

One of the major debates in cognitive neuroscience concerns the origins of the “social brain” in humans and the specialization of the brain structures involved in the social cognition. The ability to detect and recognize faces is commonly considered to be a good example of human perceptual abilities involved in the good adaptation of humans as social animals and represents the most studied aspect of the infant social brain. In fact faces provide social information as identity and emotions used by humans during the social interpersonal communication just a few hours after birth (Valenza, Simion, Macchi Cassia & Umiltà, 1996; Farroni, Menon, Rigato & Johnson, 2007; de Haan, & Nelson, 1997). In this view some authors have speculated that the preferential responding to faces observed in newborn may be mediated by subcortical visuomotor pathway, whereas later developing abilities to recognize individual faces are mediated by the ventral stream of visual cortical processing (Johnson, 2005; Farroni, Simion, Umiltà & Dalla Barba, 1999). With regards to this findings Morton and Johnson (1991) suggested that the newborn bias for the special stimulus “face” is mediated by subcortical visuomotor pathway because the newborn preference for faces found at the same age of other newborn's reflexes assumed to be under subcortical control, because of evidence from the maturation of the visual system indicating later development of cortical visual pathways and because of evidence from another species as the domestic chick. (Rosa Salva, Regolin, Vallortigara, 2010; Rosa Salva, Farroni, Regolin, Vallortigara & Johnson, 2011). So, an accredited view suggested that newborns pay more attention to conspecifics due to subcortical pathways involved in the orienting the attention toward social stimuli. This provides an appropriate input to the cerebral cortex for its development and specialization during the firsts months of life (Johnson, 2005). In accordance with interactive specialization perspective ERPs studies on the neural basis of face processing suggest that there is a gradual cortical specialization during the infancy due to the maturational aspects of the cortical structures and the interaction with the social environment (Johnson, 2001; Johnson, Griffin, Csibra, Halit, Farroni, de Haan, Baron-Cohen & Richards, 2005). Functional magnetic resonance imaging (fMRI) evidence suggests that the cortical specialization for face perception observed in adults emerges gradually over the first decade of childhood in part as a result of the experience and in part as a result of initial biases (Cohen Kadosh & Johnson, 2007). Another attribute of the adult social brain, relative to face processing, is the capacity to process information about the eyes of other humans. In particular human adults are able to process two important aspects of the eye gaze: the eye-gaze cueing[2] and the eye-contact[3] which are essential for effective communication in regard with averted gaze (Farroni, Csibra, Simion & Johnson, 2002). To investigate how behaviourally preference for mutual gaze and capacity to follow gaze are implemented in the infant brain Farroni and colleagues tested four months-old infants using ERPs. The results showed increased amplitude of the N290 in response to faces with direct gaze than with averted gaze in the infant brain (Farroni et al., 2002). This finding is obtained even when the head is averted but direct mutual gaze is maintained (Farroni, Johnson & Csibra, 2004). However, enhanced neural processing of faces with direct gaze is only found when eyes are presented in the context of an upright face.

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[2] The ability to detect the direction of another’s gaze in order to direct the attention to the same object.

[3] The ability to detect direct gaze, enabling mutual gaze with the viewer.

The amplitude of the N290 is modulated by eye gaze (Farroni et al., 2002, 2004) and face orientation (de Haan, Pascalis & Johnson, 2002) in infants, whereas adult N170 is only affected by face inversion, but not by gaze direction (Taylor, Itier, Allison & Edmonds, 2001). This difference in the response of the infant N290 and the adult N170 suggests that face and eye gaze share common patterns of cortical activation early in ontogeny, which later partially dissociates and becomes more specialized (Johnson, 2001). These findings suggest an early functioning of the brain structures involved in perceiving other humans. This functioning in infants may be broadly tuned and less specialized than in adults. Having this network at least partially functioning early in life may point to the pivotal role that social communication and learning plays in human development. Beyond face processing and eye gaze detection there are many more complex aspects of the social brain such as the perception of human action and the attribution of intentions and goals which will be described in the next paragraphs and in the experimental part together with another aspect of the social brain, the processing of the biological motion.

3. The process of the "Biological Cue"

There are in literature evidences about humans capacity to form: people seem to distinguish physical events in distinct categories and to learn and reason in terms of these categories (Baillargeon, 2005). For this reason it is possible to suppose that adults, as well as infants, possess sophisticated expectations about physical events (Aguiar & Baillargeon, 1999) due to the existence, from the birth, of a specialized mechanism which is involved in the formation of different event categories. In particular, relevant for this thesis, is the discrimination between two entities categories: the "inanimate objects" and the "animate objects”. The last one is discriminated for its biological characteristics, as its features and the kind of the movement performed. 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 (Rakison & Poulin-Dubois, 2001): 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 particular a self-produced motion provides one of the most powerful cues about what makes an object “animate”, a type of object different from the ones that can be put into motion only by result of physical contact. This idea dates back to at least Aristotle (Physics) and it has been incorporated, with some important specifications, in developmental psychological approach (Premack,1990). Developmental studies have shown that at young age infants know that stationary objects start to move if, and only if, they are contacted by another moving object, unless provided with an inner mechanism that permits self-produced motion.(Luo and Baillargeon, 2005) To process an object as “animate” is the first step to form expectations about the physical property of the object. The animate objects comprehend also the most social specialised animate object which moves in the physical space: the human being. The human movement is perceived and analysed by other individuals by multiple sources of information including sensory, motor, and affective processes. To perceive the motion of other objects and other individuals is crucial for the human adaptation in the social world. In particular humans, being highly social creatures, perceive what others are doing and infer from gestures and expressions what others may be intending to do. These perceptual skills are easily mastered by most, but not all, people, in large part because human action readily communicates intentions and feelings.

3.1. The processing of biological motion

People are highly adept to recognizing biological motion, the movement of humans or other animals. In the 1973 Johansson devised an ingenious method for studying biological motion without interference from shape. He attached light sources to actors' main joints and recorded their movements in a dark environment (Fig.1). He then showed the moving dot configurations to naive subjects who, rapidly and without any effort, recognized the moving dots as a walking person. In that display the critical points were marked by white dots and the rest of the body and background were black, not visible. Dynamic point-light displays allow people to understand biological motion such as working and running. Viewers can even infer characteristics such as gender, identity, personality traits, emotions, and complex actions, such as dancing from these simplified animations (Kozlowski and Cutting, 1978; Blakmore & Decety 2001).

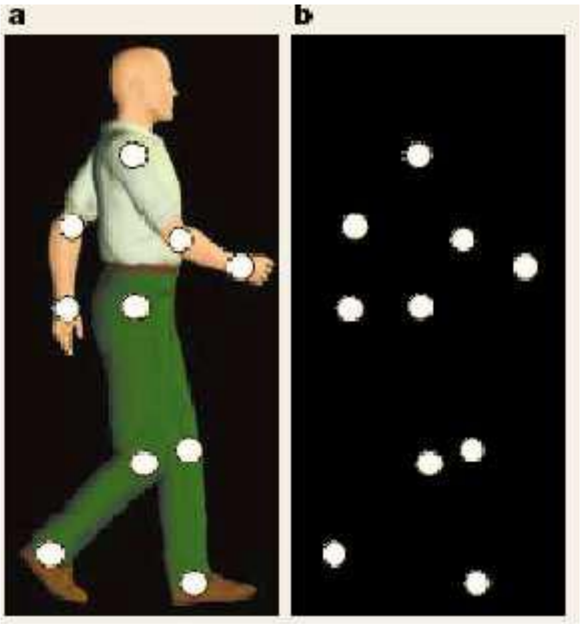

Figure 1 An example of point-light display.

Biological motion is a highly complex motion pattern and an example of the sophistication of pattern analysis in the brain. A number of neuroimaging studies combined with Johansson paradigm have examined point light biological motion perception in human brain. Grossman and colleagues investigated the neural activity associated with the perception of biological motion using functional magnetic resonance imaging (fMRI). They found a neural activation in Superior Temporal Sulcus (STS) region in response to point-light sequences depicting biological motion, but this region was not activated by scrambled versions of those point-light sequences (Grossman, Donnelly, Price, Pickens, Morgan, Neighbor & Blake, 2000). The STS may also participate in the perception of biological motion when viewing point-light simulations of hand action, body movement and not viewing random motion. A region of the STS was evidenced, also, by Puce and colleagues who found an activation in the same area in response to eye and month movements. This research aims to the existence of a region in the human brain uniquely activated by biological motion (Puce et al., 1998). Moreover recently, in a functional magnetic resonance imaging (fMRI) study, point-light biological motion has additionally been found to activate premotor and inferior frontal regions involved in action planning and execution (Saygin, Wilso, Hagler, Bates & Sereno, 2004).

Detecting the biological motion and its direction is a critical point for the adaptive behaviours of different animals species. It is supposed that some vertebrates have, like humans, a primitive brain system for the visual detection of other vertebrates. Supporting this view Vallortigara and Regolin displayed upright and inverted point-light images depicting a walking hen to naïve chicks. The results indicated that chicks tended to align their body along the apparent direction of motion of an upright point-light hen, but not to an inverted hen. These findings support the idea of an evolutionarily ancient neural mechanism for detecting other legged vertebrates as well as evidence about specific neural systems activated by the perception of biological motion in mammals (Vallortigara & Regolin, 2006). Moreover an inborn predisposition to biological motion was supposed in the ontological development supporting Johansson's idea suggesting that detection of biological motion could be an intrinsic capacity of the visual system. Newborn babies of two days of life were presented with two different point-light displays operating either a biological motion or non biological (random) motion and they were able to discriminate between them and manifested a spontaneous preference for the biological motion display even if showing an unfamiliar shape representing a walking hen. Even more interestingly, the results demonstrated that the preference for biological motion was orientation specific. Newborns showed to prefer upright compared to inverted biological motion displays (Simion, Regolin & Bulf, 2007). The authors stressed the intrinsic newborn’s capacity to process biological motion. The very young age of our subjects excluded that the biological motion stimulus could represent a familiar shape (such as a human body). It is also unlikely that newborns at the time of the test had any experience of human walking and it can certainly be excluded that they had any previous experience of walking hens. Starting from EPRs data about the processing of face perception (see paragraph 3) recent studies investigated the modifications in the neural activity in response to biological motion in young infants hypothesizing that similar electrophysiological substrates might be involved in processing point-light display stimuli. In these studies eight months old infants were presented with an animation video employing a point lights display representing a walking human, during the animation presentation an ERP measurement was taken. The results suggested a neural activation in the right parietal region like in adults (Hirai & Hiraki, 2005; Reid, Hoehl, & Striano, 2006) demonstrating an early brain activation for the processing of biological motion in humans.

3.2. The processing of the non-biological motion

The study of the non-biological motion had not encountered much interest in developmental psychological literature. Usually researchers investigated the role of movement as one of the major characteristics in physical world knowledge. These investigations were limited to self-propelled movement in presence of objects with or without biological features. As described above, the self-propelled movement has been one of the basic assumptions to categorize objects versus social objects in the world. But it is possible to distinguish a non biological movement which is mechanical independently from the object features. When people are presented with a movement operated by a human and with a movement operated by a machine he or she can perceive crucial differences in the cinematic and in the perceptual aspects of the motion. Biological movements are usually fluid, harmonic, with regular acceleration and deceleration due to the body characteristics of vertebrates, whereas mechanical movements present a rigid execution and they will be always operated in the same identical way. In contrast biological motion, typical movement of human and animal beings, has a particular flexibility in its functions in order to form motor programs adaptable to different social situations. Above, in paragraph 1 it was described that infants are able to categorize objects as animated and inanimate. A fundamental cue to identifying animate object is the kind of movement and in particular the capacity of a self-propelled motion. This is the object ability to move in an independent way, to start the motion, to stop and to act in an intentional way. Inanimate objects, if they are not social objects, do not present this characteristics, they need an external stimulation to start their motion and for this reason they do not appear to move in an intentional way (Premack, 1997; Premack & Premack, 1997).

CHAPTER 3

AN ASPECT OF THE SOCIAL BRAIN: THE DEVELOPMENT OF THE PERCEPTION OF OTHERS AS INTENTIONAL AGENTS

The animal's survival depends on its ability to identify the movements of prey, predators and mates and to predict their future actions, the consequences of which are radically different and could in some cases be fatal. As social animals, humans behave largely on the basis of their interpretations and predictions about the actions of others. Humans have an inherent tendency to interpret the actions of others in terms of goals and to infer other people's intentions from their actions. Children, as well as adults, tend to interpret other people's behaviour as goal-directed actions and then they extend these interpretations to the behaviour of other animals, humans and sometimes to inanimate moving objects. Evidences suggest that, by the end of the first year of life and just from the sixth month of age, infants are able to interpret observed actions in terms of goals (Meltzoff, 1995; Gergely, Nádasdy, Csibra, & Bıró, 1995; Woodward & Sommerville, 2000). For this reason in this chapter the comprehension of goal-directed actions in the first year of life and the neural basis involved in this process will be described.

1. Goal-directed actions : Agency, Animacy, Intentional Agency and the Teleological Stance

Agency, Animacy and, Intentional Agency

A goal-directed action is not just a psychical action. It is possible to consider an action goal-directed if it is performed in order to bring about a change of state in the world, if it is a means to an end. Several researches have tried to distinguish the features that characterize an object which can act in a goal directed way and which is usually called "an agent". In this context "agency" is described at different levels (Carey, 2009). The first and basic level is the "mechanical agency", called "animacy", which refers to entities that are capable of self-propelled motion. The concept of "mechanical agency", therefore, belongs to the domain of naïve physics and it seems to lie outside the psychological domain of intentions (Leslie, 1994; Csibra, Gergely, Bíró, Koos and Brockbank, 1999).

The second type of agency concerns the behaviour of animate objects and it is called intentional agency (entities with goals, attentional states, capable of perception and mental states like beliefs and desires) where self-propulsion is recognized as a sufficient cue for intentional agency detection. Animate objects are therefore regarded as "intentional agents", capable of attending and perceiving other objects and of setting themselves goals (Carey, 2009). So, it is possible to observe 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, called "mentalistic 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 (Johnson, 2000).

Teleological stance

However the ability to detect goal-directed actions does not entail the ability to attribute intentional agency to an actor (Csibra, 2003, Gergely, et.al, 1995; Gergely & Csibra; 2003). Gergely and Csibra argue that there is another important factor which needs to be taken into account in understanding intentional actions and they proposed a teleological representational system at the basis of infants perceptions of goal-directed actions which does not entail agency contribution. Gergely and Csibra started from the "principle of rational action" that is defined as "states that an action can be explained by a goal state if, and only if, it is seen as the most justifiable". This principle called "teleological stance" is akin to the intentional stance of Dennett (1987) which represents an interpretative strategy that seeks to construe an event in terms of goals in accord with a certain formal structure. Construing an action as goal-directed implies relating at least three different aspects of the observed event to each other: the behaviour, its physical context and the end state (Fig.2). These three elements will create a well-formed teleological representation of the event if, and only if, the behaviour is an efficient action towards the end state in the given physical environment. The agents behave in a *rational* manner, otherwise people would not be able to predict from their beliefs and desires what particular action they can be expected to perform. The rationality assumption predicts that an agent will carry out the most effective or rational action available. A goal-directed action is represented in terms of a teleological interpretative schema containing three elements: the observed behavior, a possible future state (future in relation to the behaviour) and the relevant aspects of physical reality that constrain possible actions. This schema provides a *well-formed* teleological representation only when the observed behavior can be considered as an effective (rational) way to bring about the future state given the physical constraints of the particular situation. If this well-formed condition (articulated by the rationality principle) is satisfied by the representation in question, the future state will become encoded as the goal, the behavior as a means to the goal, and the relevant aspects of physical reality as action constraints. Therefore, it is the principle of rationality that specifies the well-formed conditions which, when satisfied, relates together the three elements of the representation of the teleological schema, creating the interpretation of the observed behaviour as a goal-directed action.

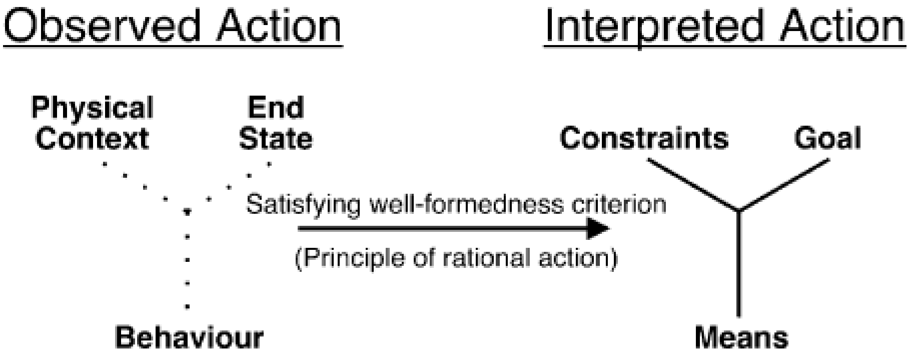

Figure 2 The three-part structure of the Teleological Stance (Csibra, 2003).

1.1. Experience based theory

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 agency attribution. Most of these studies investigated whether infants would pay attention selectively to aspects of an action 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). They have suggested that infants' ability to reason about goals is developed as a result of their experiences with human agents and is then gradually extended to other agents. This view predicts that young infants should attribute goals to humans, but not to other inanimate objects (Woodward 1998). In this work infants (5, 6, and 9 month-old) were presented with an habituation/dishabituation paradigm in which they saw an actor reach for and grasp one of two toys. After the habituation the position of the two toys were switched and the infants saw the test events in which there was a change in either the path way of the motion taken by the actor or the object grasped by the actor. 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). During the test each event preserved only one of those dimensions (Fig.3). 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. By 5 months of age infants showed increased looking time (a response to novelty) on "new-goal" trials, but not on "new-path" way trials. This result were in line with the hypothesis that infants had intended the original habituation action in terms of goal-directed behaviour (Woodward, 1998). In experiments like this one, critically, infants do not respond in this way when the moving entity is not a hand, but an inanimate object like a toy and not readily identified as an agent (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-directed.

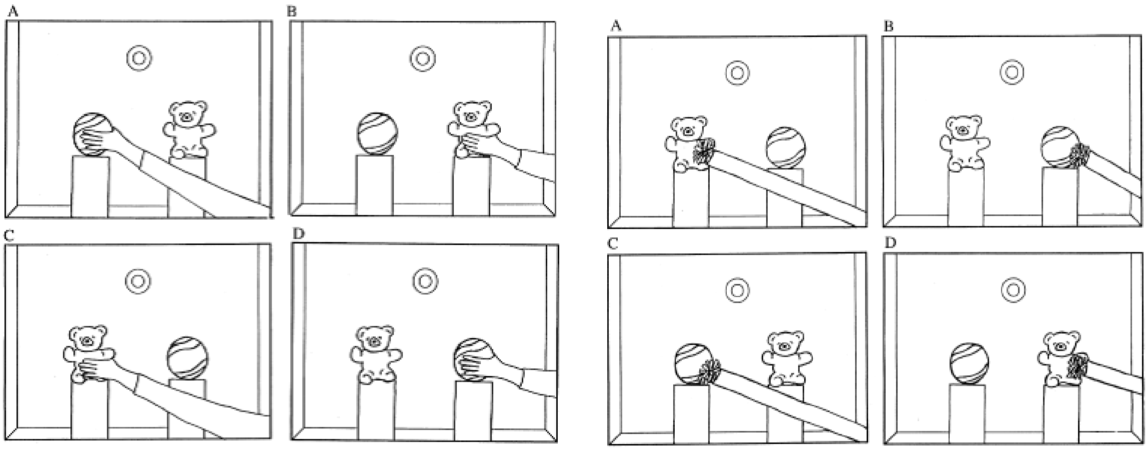

Figure 3 Stimuli used by Woodward in her researches. Infants were habituated to either event A or B and then presented with C or D at test. In case of habituation to A, C would be the “novel goal-same path” event, D would be the “same goal-novel path” event; viceversa in case of habituation to B (from Woodward, 1998).

1.2. Cue based theory

Contrary to the Experience Based theory describe above other researchers have proposed that goal attribution is rooted in a specialized system of reasoning which is activated whenever infants encounter entities with appropriate features (e.g., self-propulsion); these researches predict that young infants, as adults, should attribute goals to both human and nonhuman agents. Luo and Baillargeon (2005) provided support for the view that from an early age infants attribute goals to any entity they identify as an agent. They proposed another possible interpretation for the Woodward's findings. They explained that the rod used in the Woodward's study extended from a window in the right side of the apparatus, its right end was hidden from view, making it unclear whether its actions were externally or internally caused (although the actor's arm in the initial experiment also extended from the right side of the apparatus the infants no doubt recognized that it belonged to a person and so viewed its actions as internally caused). This interpretation suggests that 5 month olds may attribute a goal to a nonhuman agent if given unambiguous evidence that they are indeed faced with an agent. For this reason 5 month-old infants were presented with a box that moved back and forth across an apparatus floor. It was clearly capable of self-propulsion because it initiated its motion in plain view and reversed direction repeatedly. In the experimental apparatus a cylinder and cone were placed respectively on the left and right sides of the apparatus and the infants received familiarization trials in which the box moved towards and rested against the cone. Next, the infants received a display trial in which the positions of the cone and the cylinder were reversed. Finally, the infants received test trials in which the box approached and rested against the cone (old-goal event) or the cylinder (new-goal event). The results suggest that 5 month-old infants categorized the box as an agent and interpreted the box actions as directed towards the goal. They repeated the same experiment introducing a handle attached to the box. For half of the infants the handle was short and remained within the apparatus (short-handle condition); for the other infants the handle was long and extended through the window in the right side of the apparatus (long-handle condition). The results showed that the infants in the short-handle condition identified the box as an agent and they again looked longer at the new than at the old-goal event; in contrast, the infants in the long-handle condition did not perceive the box as an agent and they looked at the two test events equally. These findings suggest that the infants did not categorize the box as an agent when its handle extended out of the apparatus, making it unclear whether it moved by itself or not. Because the infants did not perceive the box as an agent, they did not interpret its actions as goal-directed. Also other researches support this second view. Biro and Leslie in the 2007 emphasize the role of observing behavioural cues in the goal-directed action comprehension. They used an apparatus similar to the one used by Woodward (2005) and in four experiments they investigated the nature of goal-directed action interpretation in infancy. In particular, the experience-based and the cue-based accounts were contrasted by examining certain action characteristics that are assumed to be critical in goal-attribution by one or the other account. Three main questions were raised. One concerned the familiarity of the action. They found that infants as young as 6 months old can consider an action goal-directed even if the action is not likely to occur in their everyday life and if they cannot perform it themselves. This finding does not comport with the experience-based approach: infants do not necessarily have to acquire prior, hands-on experience with particular actions in order to be able to encode the goal of the action. The second question concerned the perceptual appearance (animate vs. inanimate) of the actor. The authors found that12-, 9- and even 6-month-old infants can consider the action of both types of actors as goal-directed. The third question concerned the influence of behavioural cues on infants' ability to infer the goal of an action. Three cues were used that have been widely suggested in the literature as critical to goal-attribution: self-propelledness, equifinal variations of the action, and a salient action-effecttheir and the results suggested that also 6 months-old infants can encode the goal object of an inanimate action if the behavioural cues (equifinality of the action, self-propelledness and an action-effect) are present (Biro and Leslie 2007). In the Experiment 1 Biro and Leslie tested 12, 9 and 6 months old infants using the Woodward's paradigm, moreover they introduced a behavioural cue "the equifinal variation" which was a poking action carried out in a manner that indicated that the actor (animate and inanimate) was able of equifinal variations of behaviour (Fig. 4). In the "Poking Hand" condition all infants evaluated the goal-directeness of the action in contrary to the "Poking Tube" condition.

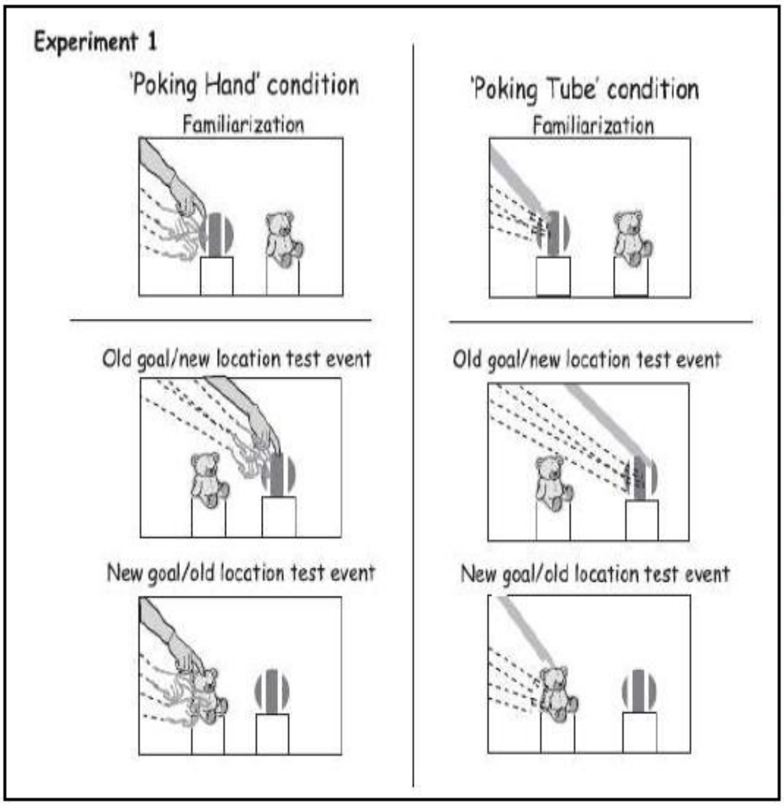

Figura 4 Stimuli used in the Experiment 1 (Biro & Leslie, 2007)

Probably infants did not comprehend the goal-directed in the "Poking Hand" condition because the human hand was more flexible than a paper tube and the variations of the hand's movement might have been more apparent than those of the paper tube. This difference may have resulted in not having the behavioural cue effectively available in the Poking Tube condition. For this reason, in the Experiment 2, the authors used a wooden rod as inanimate actor and they introduced two behavioural cues in the familiarization event: the rod demonstrated to be self-propelled and exhibited an action-effect touching, lifting up and the replacing the object (Fig. 5). The results reveal that 12 months old infants encode the goal-directed action whereas 9 months old infants showed this ability less than 12 months old infants and 6 months old babies were not able to evaluate the goal-directeness of the inanimate action

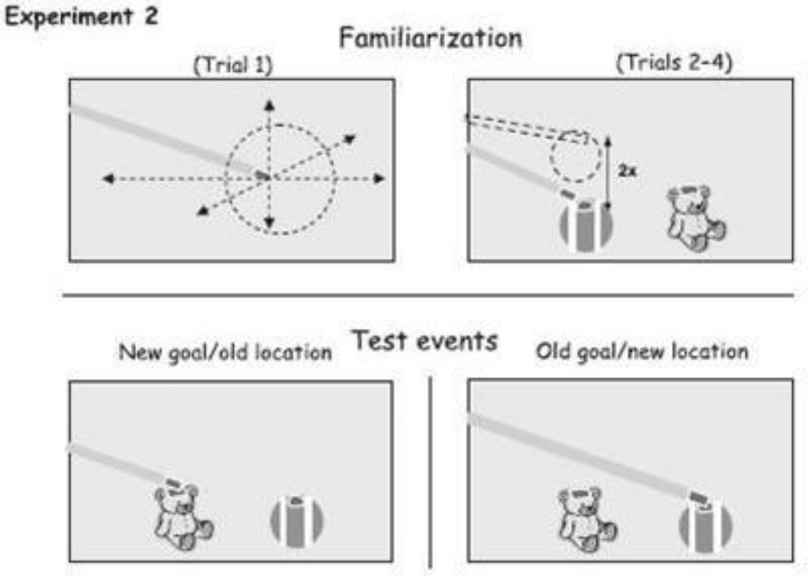

Figure 5 Stimuli used in the Experiment 2 (Biro & Leslie, 2007)

The Experiment 3, 9 and 6 months old infants were tested replicating Experiment 2. The stimuli were the some except that the rod not only touched but also picked up the toy in the test events. That is, the action effect cue was available in both the familiarization phase and in the test events (Fig.6). When the rod not only touched but also picked up the toy in the test event, the infants expected the rod’s action to be directed to the same target object as in the familiarization. 9-month-olds benefited from direct perceptual evidence for the entire goal-directed action sequence in identifying the goal but the 6-month-olds, however, did not seemed to be helped by the addition of the action-effect cue to the test events.

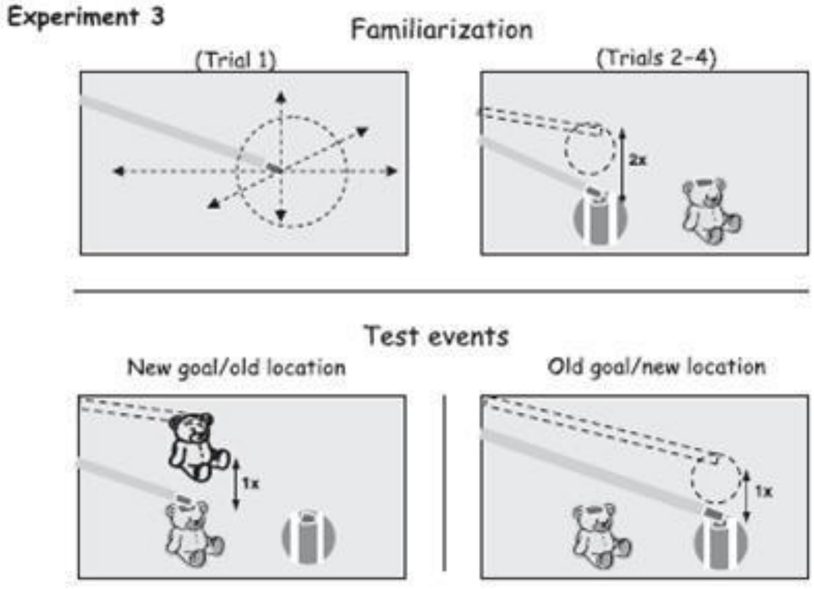

Figure 6 Stimuli used in the Experiment 3 (Biro & Leslie, 2007)

In the last experiment the author replicated Experiment 3 with the exception that a third cue, equifinal variations of the action, was added to the familiarization phase. The wooden rod approached the target toy from three different angles and picked the toy up by sticking to three different part (Fig. 7). They tested only 6 months old infants and demonstrated that also very young infants are able of interpreting inanimate actions as goal-directed if multiple behavioural cues are presented (equifinality of the action, self-propelledness and an action-effect).

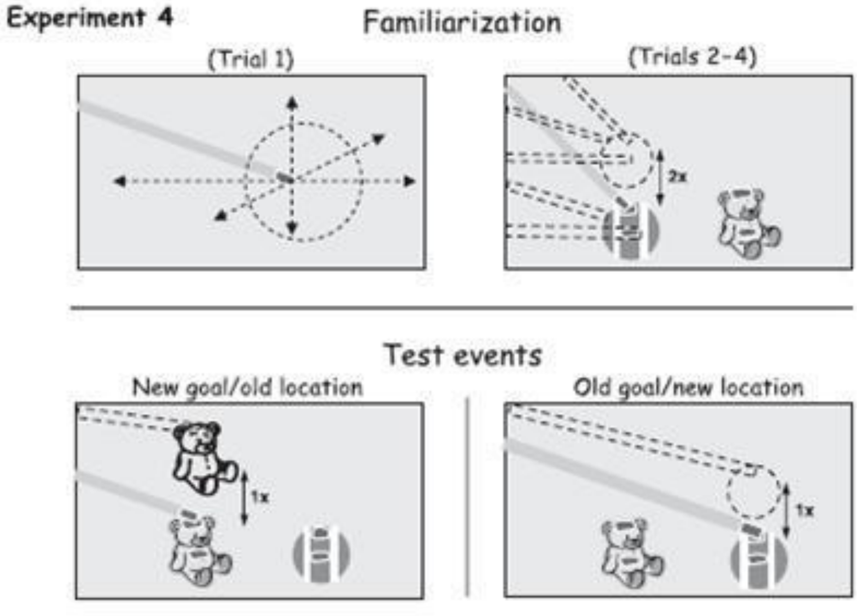

Figure 7 Stimuli used in the Experiment 4 (Biro & Leslie, 2007)

2. Neural basis of actions comprehension and the mirrors neurons

In recent years neurophysiology has investigated the neural correlates of precursors of the mechanisms that allow people to understand other people's behaviour and assign goals, intentions, or beliefs to the inhabitants of our social world. Most studies investigated these mechanisms in lower species of social primates such as macaque monkeys and in humans. The capacity of understanding the intentions of other humans might have evolved from an action execution/observation matching system of which the neural correlate is represented by a class of neurons recently discovered in the macaque monkey premotor cortex: mirror neurons (MNs) (Rizzolatti & Craighero, 2004).

The F5 neurons' responsiveness to visual stimuli

A new class of visuomotor neuron has been recently discovered in the monkey's premotor cortex: mirror neurons (MNs). These neurons respond both when a particular action is performed by the monkey and when the same action is observed being performed by another individual. Mirror neurons appear to form a cortical system matching observation and execution of goal-related motor actions. Mirror neurons, as mentioned above, activate during specific goal-related motor acts. Grasping, manipulating and holding objects are by far the most effective actions triggering their motor response. About half of them discharge during a specific type of taking, precision grip (taking of small objects by opposing the thumb and the index finger) being the most common one. On the basis of their functional properties mirror neurons appear to form a cortical system that matches observation and execution of motor actions. Experimental evidence suggests that a similar matching system exists also in humans. What might be the functional role of this matching system? One possible function is to enable an organism to detect certain mental states of observed conspecifics (Rizzolatt, Fadiga, Gallese & Fogassi, 1996).

The mirror neurons in humans

Evidences strongly suggest that an action/observation matching system similar to the one discovered in monkeys exists also in humans. The first refers to an elegant study by Fadiga and colleagues in which the excitability of the motor cortex of normal human subjects was tested by using Transcranic Magnetic Stimulation (TMS). The basic assumption underlying this experiment was that if the observation of actions activates the premotor cortex in humans, as it does in monkeys, this mirror effect should elicit an enhancement of the motor evoked potentials (MEPs) induced by TMS of the motor cortex, given its strong anatomical links to premotor areas. TMS was performed during four different conditions: observation of an experimenter grasping objects; observation of an experimenter doing aimless movements in the air with his arm; observation of objects; detection of the dimming of a small spot of light. This study provided for the first time evidence that humans have a mirror system similar to the one of monkeys. Every time we are looking at someone performing an action, the same motor circuits recruited when we perform that action ourselves are concurrently activated. These results posed the question of the anatomical location of the mirror system within the human brain (Fadiga, Fogassi, Pavesi & Rizzolatti,1995). This issue has been addressed by two brain-imaging experiments utilizing the technique of Positron Emission Tomography (PET) (Grafton, Arbit, Fadiga .& Rixxolati, 1996; Rizzolatti, Fadiga, Matelli, Bettinardi, Paulesu, Perani, & Fazio, 1996). These two experiments, although different in many respects, shared a condition in which normal human subjects observed the experimenter grasping 3-D objects. Both studies used the observation of objects as a control condition. The results showed that the grasping observation significantly activates the cortex of the left superior temporal sulcus (Brodmann’s area 21), of the left inferior parietal lobule (Brodmann’s area 40) and of the anterior part of Broca’s region (Brodmann’s area 45). The activation during the action observation of a human brain cortical sector traditionally linked with language raises the problem of the possible homologies between Broca’s region and the premotor area F5 of the monkey, in which MNs have been discovered. The idea that there is a mirror system in the brain arises from the observation that the same brain areas are activated when we observe another person experiencing an action as when we experience the same action (for a recent review, see Rizzolatti&Craighero 2004). Motor areas of the brain become active when we observe others moving and we also tend to imitate the movements of others automatically.

CHAPTER 4

EXPERIMENTAL RESEARCH

In literature there are many evidences that demonstrated the infants' sensitivity to goal-directedness features of a behaviour (Woodward, 1998; Biro and Leslie, 2007, Luo and Baillargeon, 2005). But besides the goal-directed behaviours in itself a crucial cue to intentional agency attribution is the principle of rational action (Csibra and Gergely, 1998). In this view to perceive goal-directed behaviour in itself is not explicitly predicated of an agent, in fact 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 detection of a goal-directed behaviour. In a research by Saxe, Tenenbaum and Carey (2005) for instance it is described that ten and twelve months old infants expect a human hand, and not an inanimate object to be the primary cause of an inanimate object' s motion and infants did not infer a hidden causal agent if the moving object was previously shown to be capable of self-generated motion (Saxe, Tenenbaum and Carey, 2005). Moreover 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), nine months 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.

In general researches demonstrated that by six months of life infants are capable of spontaneously represent an action as goal-directed (Woodward, 1998), 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; Biro and Leslie, 2007; 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). 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). Despite this vast amount of literature that investigated how young infants reason about the physical and social world, a matter of dispute concerns which are the properties embedded in the communicative actions understanding. In fact studies of human infants suggest that they have mechanisms for representing and reasoning about biological stimuli (i.e. persons and their actions) but also about inanimate objects and their motions. When people reason about persons they have the ability to decode social cues from biological motions (such as eye gaze, emotional expression, gestures) that allows them to comprehend others as intentional agents. The movement properties seem to be a main point to distinguish between two entities categories: the objects and the social objects which can act. In this work we investigated the different contribute of the motion in the infants' comprehension of intentional actions made by social objects. I tried to clarify who are those "social objects" whose actions infants seem to understand as intentional are. As I reported studies in literature support the hypothesis that twelve, nine and six months old infants can interpret the action of animate and inanimate objects as goal-directed (Biro and

Leslie, 2007; Luo and Baillargeon, 2005) but the role played by motion cue, the features of the agents (study 1) and the self-propelledness cue (study 2) need to be further investigate. In particular in the first study I investigate the role the nature of the movement (i.e. biological movements and non-biological movements like mechanical one), the interaction between the different kind of the movements and the features of the agent, and the role play by the goal-object. I assessed the contribution of a mechanical motion in paradigm like the one used by Woodawrd (1998) and Biro and Leslie (2007), moreover I tried to explicated what is the communicative factor present in goal-directed action studies in Woodward (1998) (i.e. the presence of a choice between two possible objects) that allow the comprehension of the intentionality. In the first study it was possible to establish that the in presence of biological cue (i.e. the features of the agent and/or the biological motion) the possible choice between two objects represent the communicative factor which allow infants to confer the intentionality in the action. Moreover the results suggest that motion features is a salient cue in identifying social objects and in classifying them as intentional agents in absence of other communicative cues. Strictly regarding of this point self-propulsion seems to be the main characteristic of the motion in an intentional action. 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 detect 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. Moreover self-propelled motion has been demonstrated to be neither a necessary nor a sufficient cue for Intentional Agency attribution (Biro, Csibra and Gergely, 2007). Nevertheless, it is well attested that self-propelled motion acts as a cue to Intentional Agency attribution, in fact seeing only the motion of an inert object, infants infer that something must have caused that motion (Saxe et al., 2005). This what I tried to clarified in the second study hypothesizing that the presence of an evident self-propelledness is necessary in order to communicate actions to be interpreted.

STUDY 1:
THE CORRELATION BETWEEN COMMUNICATIVE AGENT AND COMMUNICATIVE ACTIONS

Starting from the evidence previously described and the lack of research on the role of the biological/social and non-biological/mechanical motion, the purpose of this first study was to investigate the role played by the nature of the movement, in particular: what is the role played by the congruence between the movement and the agent's features? How does the kind of movement (biological versus mechanical movement) interact with the features of the agent (biological versus non biological) in the comprehension of the action? And what is the communicative factor which allow to understand the intentionality in the goal-directed action? I reasoned that since a motion could be biological (like the motion of a human being) or mechanical (not fluid, not harmonic, rigid, not made by human agent), its association with different features could have modified the interpretation of the goal-directed actions. So, the present study, first, assessed the role of the biological and non-biological movement in comprehending the intentionality of an action in six-months-old infants and then it explicated what is the communicative factor present in that goal-directed action studies in Woodward (1998) (i.e. the presence of a choice between two possible objects) that allow the comprehension of the intentionality. I started with two replication experiments and then three new experiments were carried out, all employing a familiarization looking technique which allowed the testing of infants' preferences for a new goal versus a new pathway stimulus by measuring the duration of their fixations on the stimulus. In each experiments six months old infants were presented with the Woodward's paradigm but, differently from it, I used only one object in the scene instead of two to investigated the communicative cue representing to the possibility to chose between two goal-objects and I used either biological and inanimate actor and movements. I used a familiarization paradigm and then, during the test phases, we encoded the looking time for the scene of a new goal and for the scene with a new grasping modality as in previous works (Woodward, 1998; Biro & Leisle, 1997).

1. General Methods

Participants

Ninety-five healthy and full-term six-month-old infants were selected to participate in the study from the family register of Padua (56 males and 39 females, range age: 178–192 days). Thirty-nine additional infants were excluded from the final sample for the following reasons: 11 infants did not complete testing due to fussiness or drowsiness activeness, 19 for inattentiveness, 12 for technical problems and 7 infants were excluded as outliers because the total looking time in test phases differenced of ±2.5 Standard Deviations from the mean of fixation time.

Infants were tested only if awake and in an alert state after parents gave their informed consent.

Stimuli and Experimental Setting

The apparatus was similar to the one used in previous experiments (Woodward 1998, Biro and Leslie 2005) but differently from the previous staged real sequence, in this case video clips of a real scene were used. The stimuli consisted of three full-color video clips, each video featuring one (in Experiment 1 and 2) or two (in Experiment 3,4 and 5) objects (i.e., a ball or a cube, red or blue) which were reached for and grasped from an actor. In the experiment 1 and 2 it was used two objects to replicate previous findings and in the experiments 3, 4 and 5 I used only one object in the scene stimulus. After a familiarization event, during the two test phases there was a change either in the path way of the motion taken by the actor and therefore called “new pathway test event” or in the object grasped by the actor and called “new goal test event”. The two possible path way used in experiment 1 and 2 were the same used in previous works and in particular they were “from the right side of the scene” or “from the left side of the scene” as in Woodward (1998). In experiments 3, 4 and 5 the two possible pathway were from the right part of the scene (lateral) or from the up part of the scene (above) It was not necessary to use the same pathway used in previous works because the presence of the presence of only one object. Infants were able to discriminated between the two different pathways. Every stimulus event stared with one or two objects on the scene, then an human or inanimate actor entered the scene, reached for and grasped one object. The two path ways, the shape and the color of the object were presented randomized between subjects. The stimuli video clips were real scene recorded by the experiment and then enhance in the luminance and contrast using the software Adobe Premiere. The human actor was a real arm and the inanimate actor was a paper tool made with the same size of the human arm. The cube was 14x14x14 cm and the ball had a diameter of 14 cm.

The video-clips were presented on a high-resolution Samsung (Flat Panel 20’’) computer monitor. The baby sat on an adapted infant car seat at a distance of about 70 cm from the monitor, the infant’s eye level was at the centre of the screen. Above the monitor, a video camera recorded the infants’ eye movements to monitor their looking behavior online and to allow off-line fixations coding frame by frame. To prevent interference from irrelevant distracters, plain blue curtains were drawn in behind the monitor (Fig.8).

Fig. 8 Experimental Setting in the baby lab room at the University of Padua

Procedure

After the infant was familiarized with the laboratory environment, he or she sat on a car seat in front of the stimulus monitor. At the beginning of each trial the experimenter drew the infant’s attention to the display by showing colored flashes on the monitor. When the baby looked at the screen, the experimenter pressed a key which started the presentation of the familiarization stimulus, then repeated continuously until the infant looked at the stimuli for 80seconds. When the infant looked at the stimuli the experimenter pressed a key on the keyboard, and if the operator did not released the key it indicating that the infant was looked at towards the monitor, the computer program calculated the msec of fixations. When the baby looked at the stimuli for 80 sec the computer program stopped the stimulus display and registered the looking time. When the familiarization criterion was reached, the stimulus was automatically turned off and a sequentially preference test phase started in which a preference could be expressed between the familiar object but using a new path way (new path way test event) and a novel object and the familiar path way (new goal test event)..In the new goal test event the object grasped in familiarization test changed and the hand direction of the motion was the same as in the familiarization. In the new path way test event the hand direction of the motion changed and the grasped object was the same as in the familiarization. The two test events were presented sequentially and the presentation was randomized between subjects.Every test event was 60 sec long, but it stopped automatically if infants looked at it for 40 sec. Eye movement data were on line coded by an experimenter, blinded of the stimuli shown, who recorded the duration of the infants' fixations on each stimulus by pressing a key. The looking time for the scene of a new goal test event and for the scene with a new grasping modality was encoded as in previous works (Woodward, 1998; Biro & Leisle, 1997). Moreover, videotapes of the infants' eye movements of the test phase were subsequently frame by frame coded by a second coder unaware of the stimuli presented (it was not possible for the coder to recognize the stimuli from the corneal reflection).

Data Analysis

Videotapes recordings of infant's eye movements of all test events were analyzed frame by frame by two coders (an experimenter and a student); both coders were unaware of the kind of stimulus presented. The coders recorded, separately for each stimulus, the number of orienting responses and the total fixation time, that is to say, the sum of all fixations. The mean estimated reliability between on-line and off-line coding was analyzed by Cohen's Kappa.

Then the number of fixations and the total looking time to each testing stimulus were recorded for each participants, to calculate the average number of fixations and the average looking time to each stimulus. To investigate whether one of the two test events was preferred over the other, two paired-sample two-tailed t-test was carried out on the infants' average looking fixation time toward the two stimuli.

2. Experiment 1

In experiment 1 we replicated previous findings (Woodward, 1998; Biro & Leslie, 1997) that suggest that infants as young as 6 months are able to discriminate goal directed actions. In particular we wanted to assess whether the infant's interest in observing an action performed by a hand is directed towards the grasping modality or towards the goal of the action when two objects are present in the scene.

Participants

A total of sixteen six-month-old infants (10 males and 6 females) participated in the experiment I. Their postnatal age ranged from five months and three weeks to six months and one week (mean age 183,2, range age: 178–192 days). Five additional infants were excluded from the final sample for the following reasons: 1 infants did not complete testing due to fussiness or drowsiness activeness, 2 for inattentiveness and 1infants was exclude for technical problems.

Test stimuli

The stimuli consisted of three full-color video clips (Fig.9).. The first video was shown in the familiarization phase. Two objects were on the scene, then a hand entered the scene, reached for and grasped one of the two objects. The hand entered the scene from the right or the left part of the screen; the objects in the scene were a blue cube and a red ball. The two path ways, the shape and the color of the object were presented randomized between subjects.. The two test phases in which was coded the infant's preference between the new goal test event and the new pathway test event started after the familiarization test. In the new goal test event the object grasped in familiarization test changed and the hand direction of the motion was the same as in the familiarization. In the new path way test event the hand direction of the motion changed and the grasped object was the same as in the familiarization. The two test events were presented sequentially and the presentation was randomized between subjects.

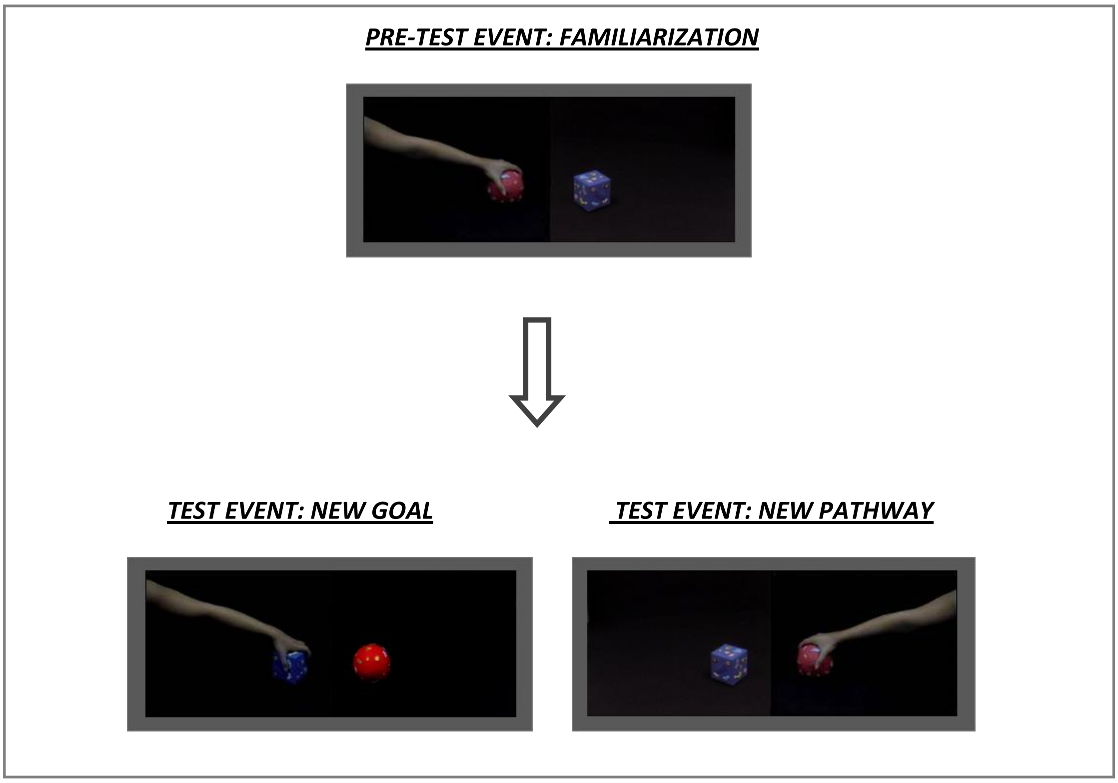

Fig.9 A schematic representation of the stimuli using in the Experiment 1

Results

The average number of fixations toward the new goal test event was (mean 8.125) whereas it was 7.37 for the new path way test event (paired-samples two-tailed *t*-test: $t_{(15)}$ = .958, p= .353).

The average total fixation time was mean = 34585 sec, standard deviation = 5188 for the new goal test event and mean = 27422 sec, standard deviation = 11773 for the new path way test event. The mean estimated reliability between on-line and off-line coding for 10% of the total participants was analyzed by Cohen's Kappa, 96% of concordance was found for the duration of fixation and 91% for the number of orientations.

Six months old infants demonstrated to look significantly longer to the new goal test event Indeed the analysis (paired-samples two-tailed *t*-test) revealed that infants looked longer at the new goal test event than at the new path test event when the hand moved in the same way as in the familiarization, but grasping a different toy ($t_{(15)}$= 2.372, p= .032), indicating that infants categorized the hand as an agent and interpreted the action as directed toward a goal confirming the Woodward's results. No significant preference emerged when considering the fixation time for object's shape and color and for the kind of path way of the motion.

3. Experiment 2

In experiment 2 as in experiment 1 we replicated previous findings (Biro & Leslie, 1997), described in chapter 3, which suggest that infants as young as 6 months, like adults, should discriminate goal directed actions and attribute goals to both human and nonhuman agents if the behavioral cues (equifinality of the action, self-propelledness and an action-effect) are present. In particular we wanted to assess whether the infant's interest in observing an action performed by an inanimate tool is directed towards the grasping modality or towards the goal of the action when two objects are present in the scene.

Participants

A total of thirteen six-month-old infants (7 males and 6 females) participated in the experiment 2. Their postnatal age ranged from five months and three weeks to six months and one week (mean age 179 days, range age: 178–192 days). Eight additional infants were excluded from the final sample for the following reasons: 2 infants did not complete testing due to fussiness or drowsiness activeness, 2 for inattentiveness, 3 for technical problems and 1infants was excluded as outliers because the total looking time in test phases differenced of ±2.5 Standard Deviations from the mean of fixation time.

Test stimuli

The stimuli are identical to the ones used in Experiment 1 except for the kind of the actor. In Experiment 2 was used a non biological actor, a tool as in the previous studies (Biro & Leslie, 1997) (Fig.10). As in experiment I also in Experiment 2 two different path ways, shapes and colors were used and no preference for one shape, color or path way was found. The video in the familiarization and in the test phases were of the same length and stopped automatically as in Experiment 1

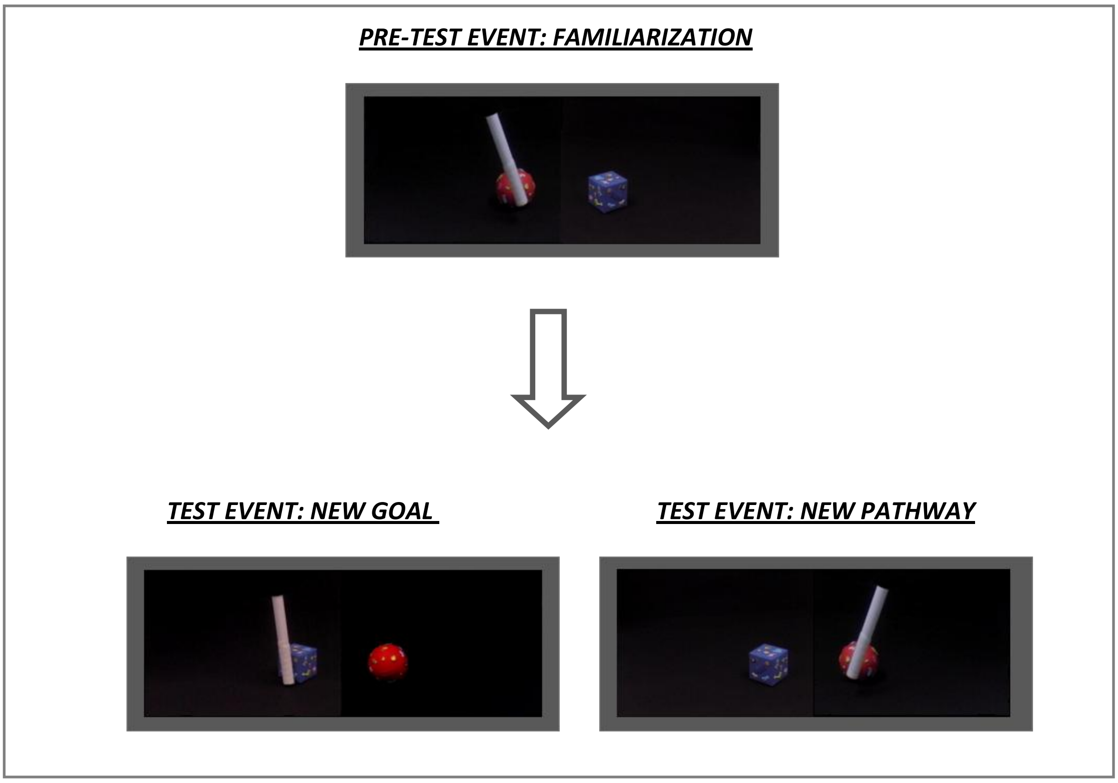

Fig.10 A schematic representation of the stimuli using in the Experiment 2.

Results

The average number of fixations toward the new goal test event was (mean 6.846) whereas it was 6 for the new path way test event (paired-samples two-tailed *t*-test: $t_{(12)} = 1.104$, $p = .291$).

The average total fixation time was mean = 33435 sec, standard deviation = 10397 for the new goal test event and mean = 29568 sec, standard deviation = 12432 for the new path way test event. The mean estimated reliability between on-line and off-line coding for 10% of the total participants was analyzed by Cohen's Kappa and 96% of concordance was found for the duration of fixation and 91% for the number of orientations.

Six months old infants demonstrated to look significantly longer to the new path way test event. Indeed the analysis (paired-samples two-tailed *t*-test) revealed that infants looked longer at the new goal test event than at the new path test event when the tool moved in the same way as in the familiarization, grasping a different toy ($t_{(12)} = 2.508$, $p = .027$), indicating that infants categorized the tool as an agent and interpreted the action of an inanimate object directed toward a goal when perceptual and behavioral cues were present, confirming previous evidence (Biro & Leslie, 1997).

No significant preference emerged when considering the fixation time for object's shape and color and for the kind of path way of the motion.

4. Experiment 3

In experiment 3 we investigated whether the presence of a choice between two objects is necessary for the comprehension of the action’s intentionality in six months old infants. Our hypothesis was aimed to demonstrate that the presence of the choice is a discriminating characteristic to the communicative role to the action. I speculated that using only one object in the scene the results of the experiment 1 and 2 and previous findings (Woodward, 1998; Biro & Leslie, 1997), which suggest that infants as young as six months old are able to discriminate goal directed actions, would not be confirmed. In particular we wanted to assess whether the infants' interest in observing an action performed by a hand is directed towards the grasping modality (lateral or from above) or towards the goal of the action in presence of only one object (Fig. 11).

Participants

A total of twenty-three six-month-old infants (12 males and 11 females) participated in the experiment III. Their postnatal age ranged from five months and three weeks to six months and one week (mean age 184 days, range age: 178–192 days). Eleven additional infants were excluded from the final sample for the following reasons: 4 infants did not complete testing due to fussiness or drowsiness activeness, 2 for inattentiveness, 2 for technical problems and 3 infants were excluded as outliers because the total looking time in test phases differenced of ±2.5 Standard Deviations from the mean of fixation time.

Test stimuli

The stimuli consisted of three full-color video clips (Fig.11). The first video was shown in the familiarization phase. Contrary to the previous two experiments (Experiment 1 and 2), the familiarization in the Experiment 3 was an object in the scene, and a arm which entered the scene, reached for and grasped the only object present. The hand entered the scene from above or from the side of the screen; the object in the scene was a cube or a ball, red or blue. The presentation of the two path ways, the shape and the color of the object were randomized between subjects. The two test phases in which was coded the infant's preference between the new goal test event and the new pathway test event started after the familiarization test. In the new goal test event the object's color and shape changed whereas the hand direction of the motion was the same as in the familiarization. In the new path way test event the hand direction of the motion changed and the object remained the same as in the familiarization.

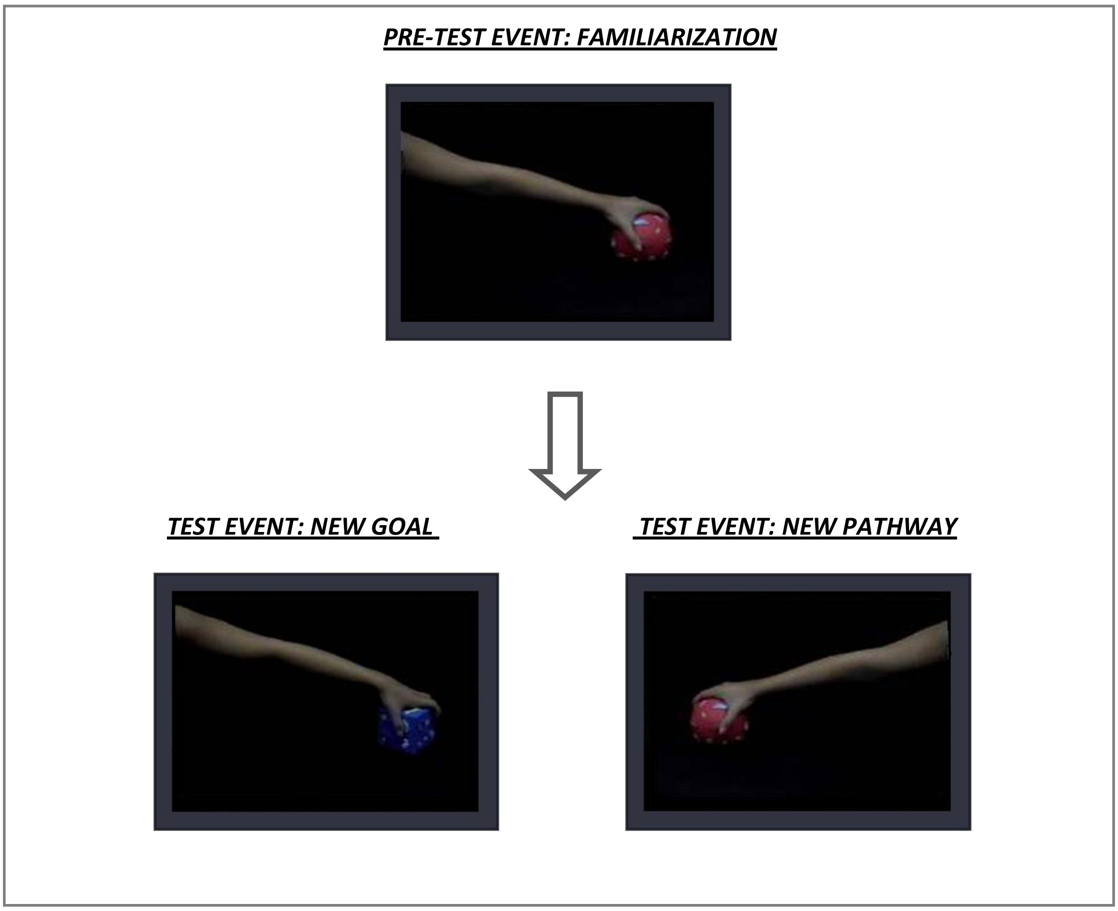

Fig.11 A schematic representation of the stimuli using in the Experiment 3

Results

The average number of fixations toward the new goal test event was (mean 7.17) whereas it was 7 for the new path way test event (paired-samples two-tailed *t*-test: $t_{(22)}$ = .117, p= .908).

The average total fixation time was mean = 32914.78 sec, standard deviation = 11655.15 for the new goal test event and mean = 34786.09 sec, standard deviation = 11632.20 for the new path way test event. The mean reliability between on-line and off-line coding for 10% of the total participants was analyzed by Cohen's Kappa and 91% of concordance was found for the duration of fixation and 84% for the number of orientations.

Six months old infants demonstrated to look longer to the new path way test event, but not significantly. Indeed the analysis (paired-samples two-tailed *t*-test) revealed that infants looked equally at the two test phases ($t_{(22)}$= -685, p= .50), indicating that young infants could not interpret the action's goal when the action was performed with only one object, contrary to previous studies which involved two objects in the scene (Woodward, 1998). We can speculate that these results support our hypothesis: the absence of a perceptual and behavioral cue like a second object in the scene could inhibit the interpretation of the actions intention.

No significant preference emerged when considering the fixation time for object shape and color and for the kind of path way of the motion.

5. Experiment 4

In experiment 4 we investigated the same thesis tested in the Experiment 3; but in this case I wanted to investigate whether the presence of the choice would be a discriminating characteristic to the communicative role of the action even if the actor was an inanimate object that moved in a biological way. The movement was fluid and harmonic and with the natural acceleration and deceleration of the biological motion because the inanimate tool was moved by an unseen person. I hypothesized that using only one object in the scene we would not confirm previous findings (Luo e Baillargeon 2005; Biro & Leslie, 1997) which suggest that infants as young as six months, like adults, can discriminate goal directed actions and attribute goals to both human and nonhuman agents if the behavioral cues (equifinality of the action, self-propelledness and an action-effect) are present. In particular we wanted to assess whether the infants' interest in observing an action performed by a tool moving in a biological motion is directed towards the grasping modality (lateral or from above) or towards the goal of the action.

Participants

A total of twenty six-month-old infants (13 males and 7 females) participated in the experiment 4. Their postnatal age ranged from five months and three weeks to six months and one week (mean age 180 days, range age: 178–192 days). Ten additional infants were excluded from the final sample for the following reasons: 3 infants did not complete testing due to fussiness or drowsiness activeness, 2 for inattentiveness, 3 for technical problems 2 infants were excluded as outliers because the total looking time in test phases differenced of ±2.5 Standard Deviations from the mean of fixation time.

Test stimuli

The stimuli in Experiment 4 were identical to the ones used in Experiment 3 except from the kind of actor, which was in this case a non biological actor, a tool as in the previous studies (Biro & Leslie, 1997) (Fig. 12). Two kinds of path way, shape and color were used and no preference for a particular shape, color or path way was found. The video in the familiarization and in the test phases were of the same length and stopped automatically as in Experiment 3.

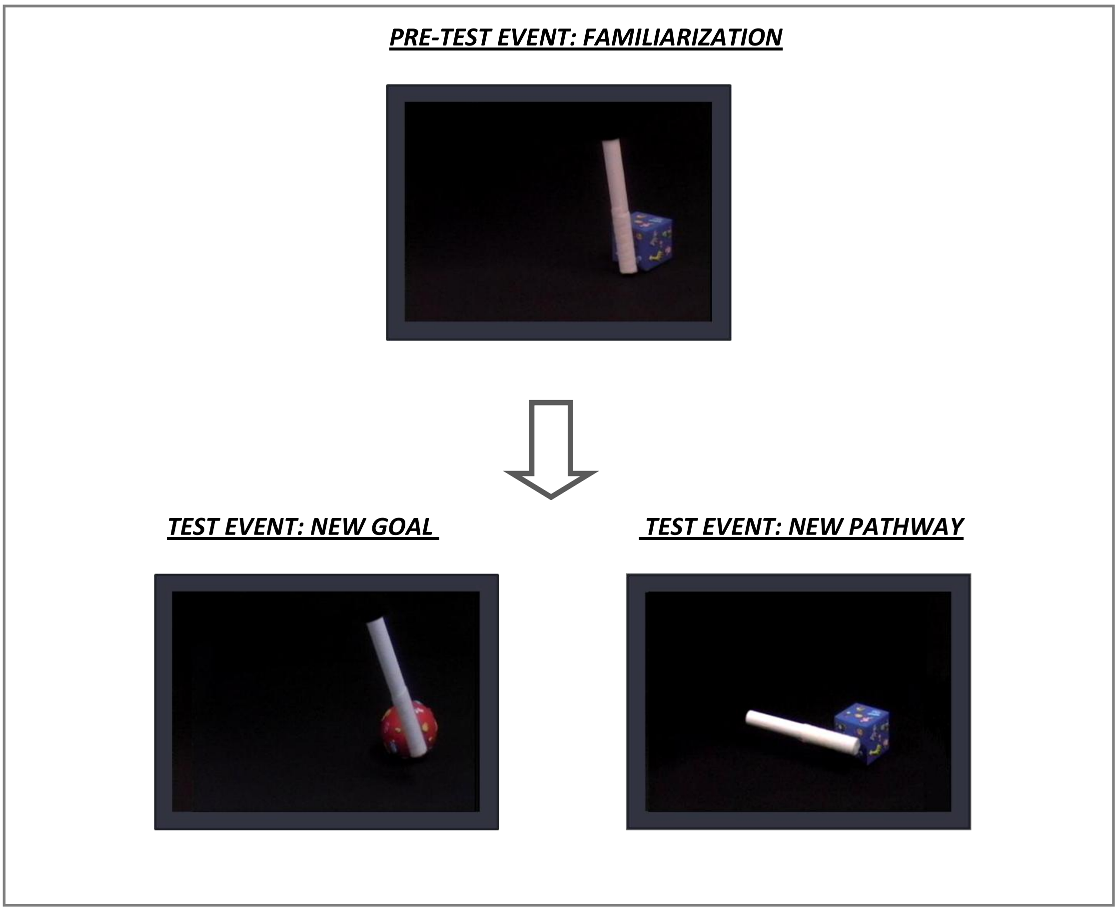

Fig.12 A schematic representation of the stimuli using in the Experiment 4

Results

The average number of fixations toward the new goal test event was (mean 6.89) whereas it was 7.42 for the new path way test event (paired-samples two-tailed *t*-test: $t_{(19)} = -.815$, p= .426).

The average total fixation time was mean = 366622.30 sec, standard deviation = 9220.898 for the new goal test event and mean = 36088 sec, standard deviation = 9487.42 for the new path way test event. The mean reliability between on-line and off-line coding for 10%

of the total participants was analyzed by Cohen’s Kappa and 96% of concordance was found for the duration of fixation and 95% for the number of orientations.

Six months old infants demonstrated to look longer to the new goal test event, but not significantly. Then, the analysis (paired-samples two-tailed *t*-test) revealed that infants looked equally at the two test phases ($t_{(19)}$= -197, p= .846). We can speculate that the absence of a perceptual and behavioral cue like the second object in the scene could have inhibit the interpretation of the actions intention. The presence of a choice seems to be necessary in order for six months-old infants to encode the goal object of an inanimate action (Biro and Leslie 2007).

No significant preference emerged when considering the fixation time for object shape and color and for the kind of path way of the motion.

6. Experiment 5

In experiment 5 we replicated Experiment 4, but we introduced a different kind of motion. We decided to use a mechanical motion congruent with the tool features. To obtain this motion we used the same video clips as in Experiment 4, but we modified the frames sequence of the video (adding frames randomly) to eliminate the fluid and harmonic characteristics of the biological motion and to modify the natural acceleration and deceleration of the biological motion. In this way we impaired the nature of the biological movement. We expected that the nature of the movement could interfere with the discrimination of goal-directed actions and in the attribution of goals to nonhuman agents in presence of behavioral cues like equifinality of the action, self-propelledness and an action-effect. In particular we wanted to assess whether the infants' interest in observing an action performed by a tool which moved in a non-biological motion was directed towards the grasping modality (lateral or from above) or towards the goal of the action in presence of only one possible choice (one object).

Participants

A total of twenty-three six-month-old infants (14 males and 9 females) participated in the experiment V. Their postnatal age ranged from five months and three weeks to six months and one week (mean age 185,28 days, range age: 178–192 days). Six additional infants were excluded from the final sample for the following reasons: 1 infant did not complete testing due to fussiness or drowsiness activeness, 1 for inattentiveness, 3 for technical problems 1 infant was excluded as outliers because the total looking time in test phases differenced of ±2.5 Standard Deviations from the mean of fixation time.

Test stimuli

The stimuli were the same used in Experiment VI and modified as described above to obtain the mechanical movement (Fig.13). Also in this Experiment two kinds of path way, shape and color were used and no preference for one shape, color or path way was found. The video in the familiarization and in the test phases were of the same length and stopped automatically as in Experiment 4.

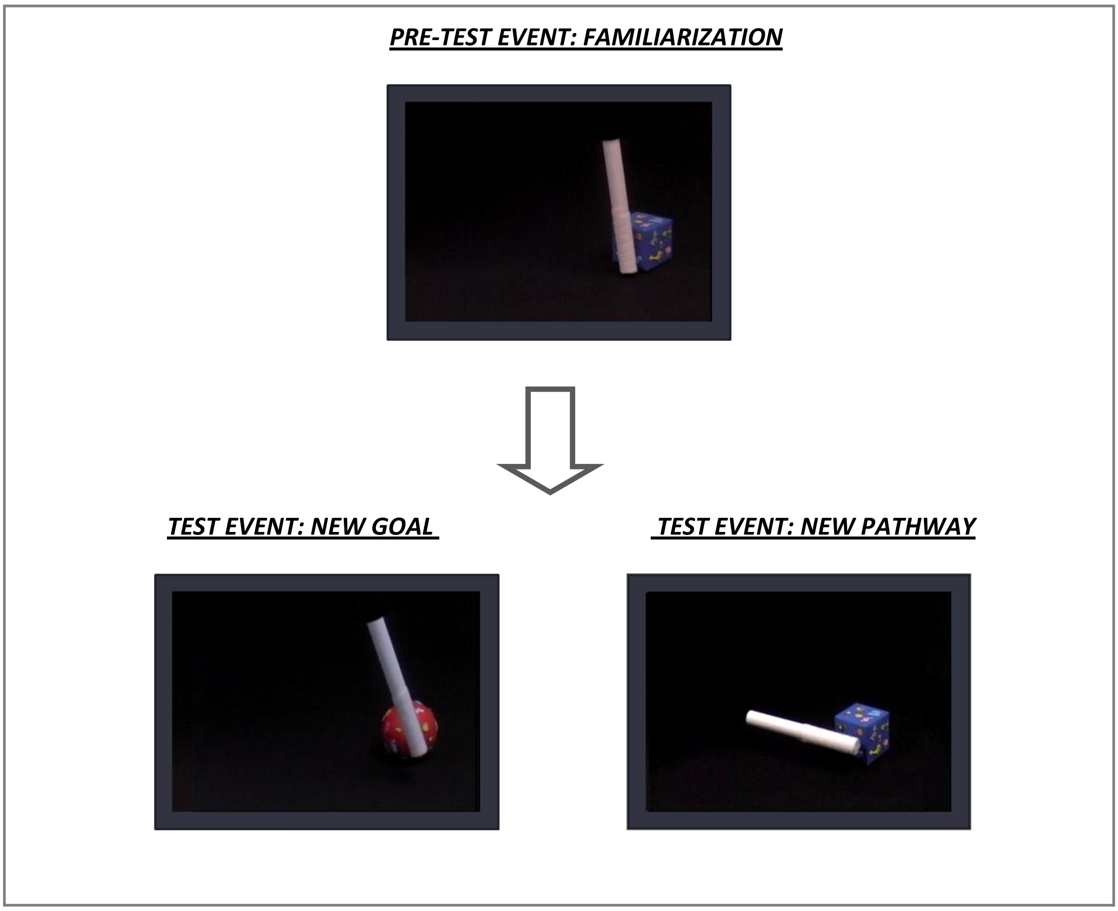

Fig.13 A schematic representation of the stimuli using in the Experiment 5.

Results

The average number of fixations toward the new goal test event was (mean 8.313) whereas it was 7.86 for the new path way test event (paired-samples two-tailed *t*-test: $t_{(22)} = .339$, p= .738).

The average total fixation time was mean = 37031.30 sec, standard deviation = 9723.52 for the new goal test event and mean = 30820 sec, standard deviation = 11821.04 for the new path way test event. The mean reliability between on-line and off-line coding for 10% of the total participants was analyzed by Cohen's Kappa and 96% was found for the duration of fixation and 91% for the number of orientations.

Six months old infants demonstrated to look significantly longer to the new goal test event. Indeed the analysis (paired-samples two-tailed *t*-test) revealed that infants in the non biological tool condition looked longer at the new goal test event rather than at the new path test event when the actor moved in the same way as in the familiarization, but grasping a different toy ($t_{(22)}$= 2.628, p= .015), indicating that infants categorized the tool that moved in a mechanical way as an agent and interpreted the action as directed toward a goal. No significant preference emerged when considering the fixation time for object shape and color and for the kind of path way of the motion.

7. Overall analysis and discussion

The study above confirms the previous findings by means of experiments 1 and 2, which predict that young infants, like adults, can attribute goals to both human and nonhuman agents. Then an analysis of variance conducted for the experimental part (Experiment 3, 4 and 5) on the looking times for each trial with conditions (hand versus biological tool versus mechanical tool) as the between subjects factor and trial type (old goal/new path way versus new goal/old path way) as the within subjects factors revealed a non significant condition trial type interaction (F(2,63) = 2.641, p = .079) and a non main effect of trial pair (F(1,63) = 1.162, p = .285), the only significant result is the difference in the looking time for the two test phases in the tool mechanical condition as described above (see Fig.14).

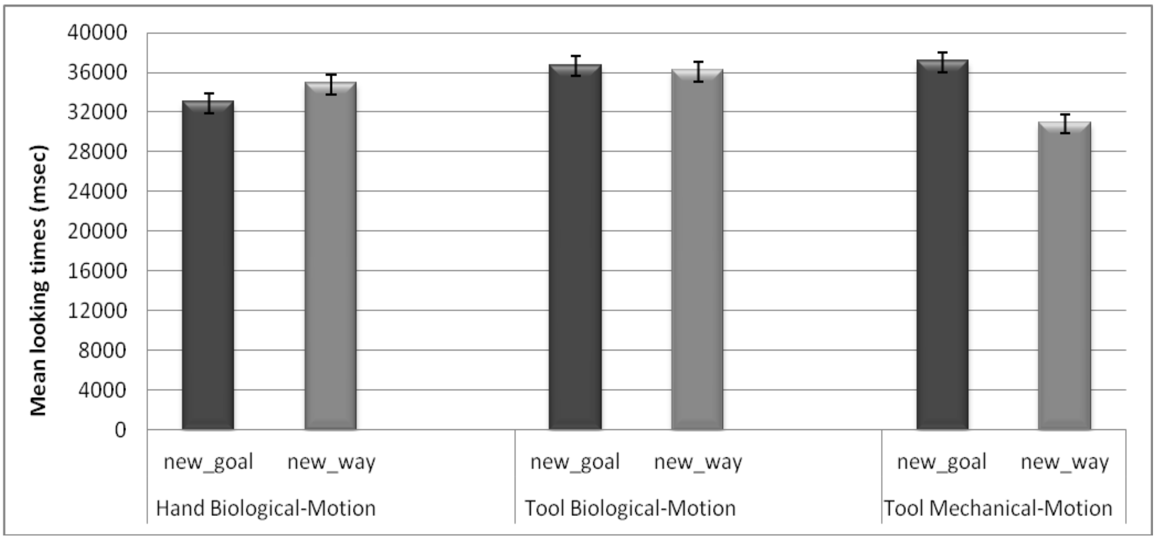

Fig.14 Overall results. Average fixation time (msec) spent by the infants looking the two test events in the experimental part of the study (Exp 3, Exp 4, Exp 5).

Overall analysis Biological Agent versus Inanimate Agent

An analysis of variance carried out on the looking times for the two different kinds of agent (hand versus tools) as the between subjects factor and trial type (old goal/new path way versus new goal/old path way) as the within subjects factors revealed a non significant condition trial type interaction (F(1,64) = 2.914, p = .093) and a non main effect of trial pair (F(1,64) = .284, p = .596). It showed that the different kinds of agents' features is not a main cue to the infants' comprehensions of goal-directed actions (Fig.15).

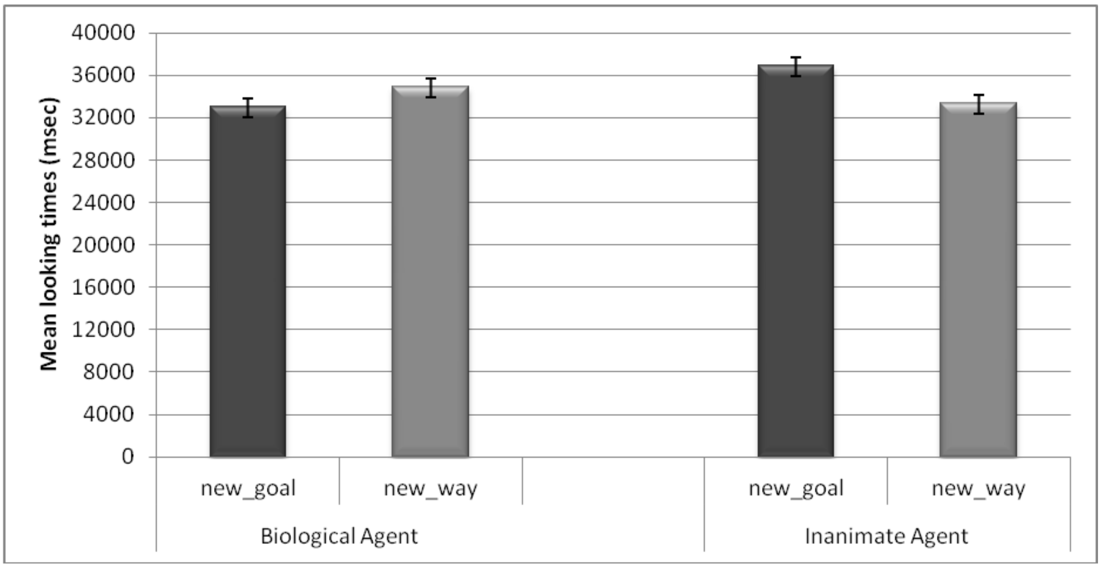

Fig.15 Overall results. Average fixation time (msec) spent by the infants looking at the two test events comparing the biological agent (hand) versus the inanimate agent (biological-tool and mechanical-tool).

Overall analysis Biological Motion versus Non-Biological Motion

An analysis of variance conducted on the looking times for the two different kinds of motion (biological versus mechanical) as the between subjects factor and trial type (old goal/new path way versus new goal/old path way) as the within subjects factors, revealed a significant condition trial type interaction (F(1,64) = 4.913, p = .030) confirming the hypothesis that the different kind of motion can modify the interpretation of goal directed actions when the communicative cues of the actions are manipulated (Fig.16).

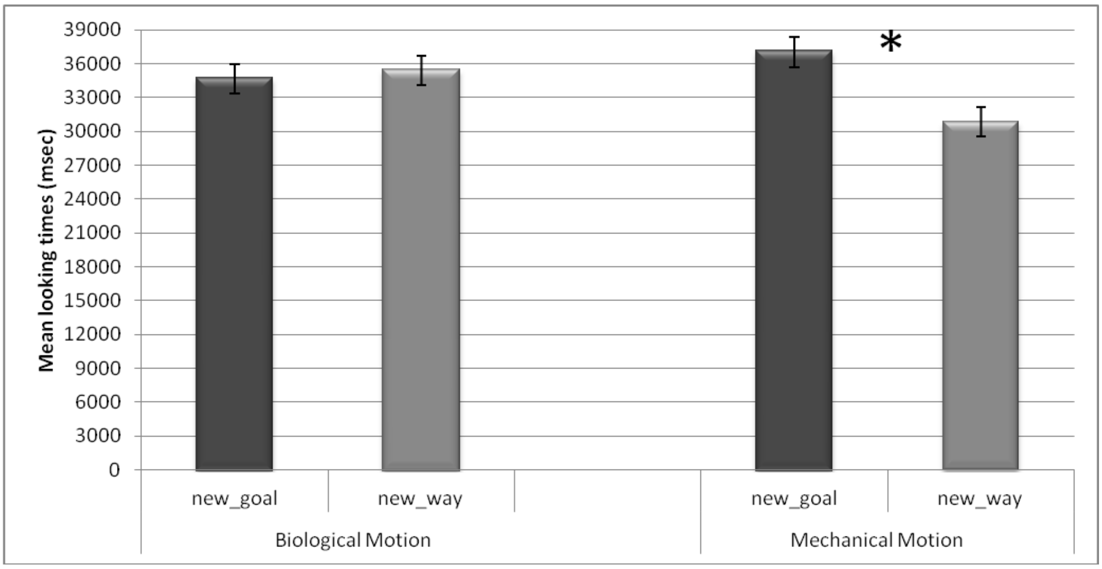

Fig.16 Overall results. Average fixation time (msec) spent by the infants looking at the two test events comparing the biological movement (hand and biological tool) versus the non-biological movement (mechanical-tool).

Indeed the results of the experimental part (experiments 3, 4 and 5) revealed that different kinds of motion can modify the interpretation of goal directed actions. The presence of a biological motion is the first and main cue to categorise an object as a social one. Therefore infants expect the social object to act in a communicative way. The communication ability of the actions vanishes when there is not a possible choice in the actions. We can notice that the results of experiments 3 and 4 revealed that when we use only one object in the scene eliminating therefore the presence of the choice in the hand as well as in the biological tool condition infants looked equally on the new goal test event as in the new pathway test event. The presence of a biological motion in these conditions seems not to be sufficiently informative for the infants to understand the intentionality in absence of a choice between two possible goal-objects, actually in this situation the biological movement makes less salient the fact that the action is goal directed. The presence of a choice is a discriminating characteristic to give a communicative role to the action, in its absence the action is just an action without any intentional and communicative role. As a matter of fact the natural-biological movement invests the actor of an intentionality that is not expressed by the action because of the absence of the two possible goal-objects.

Contrary to these results, the mechanical tool condition revealed that the presence of a non-biological motion allowed the infants to understand the scene as an intentional one even if only one goal-object was presented in the scene. The use of a mechanical motion did not give the expectation that the tool could act in a communicative way and did not attribute self-intentionality to the agent. This could have attracted the infants because of the inconsistency of therefore to pay more attention to the scene and process the two different goals present in the familiarization event as well as in the new goal test event, attributing the intentionality to the agent after watching the complete action.

We can conclude that the characteristics of the motion are the main communicative cues interpreted by infants to categorise the objects and to interpret communicative actions.

STUDY 2:

THE ROLE OF SELF-PROPELLED MOTION IN COMMUNICATIVE ACTIONS

In the second study we tested one of the characteristics of the movement recognised as used for identifying goal-directed actions which is self-propelledness (See chapter 2). The presence of self-propelledness was proposed by some (Premack, 1990; Baron-Cohen, 1994) as a precondition for setting up a goal-directed interpretation: only when an object motion is self-propelled infants consider other cues relevant for identifying the goal of the action. In an important demonstration, Luo and Baillargeon (2005), using the Woodward paradigm, showed that 5-month-old babies attributed goals to an object which motion seemed to be self-propelled. Nevertheless, self-propelled motion has been later demonstrated to be neither a necessary nor a sufficient cue for Intentional Agency attribution. In a research Biro and colleagues demonstrated that for 12-month old infants self-propulsion is not a necessary prerequisite for goal attribution and its absence does not necessarily inhibit the interpretation of behaviours in terms of goals (Biro, Csibra and Gergely, 2007). We started replicating this last work (Biro, Csibra and Gergely, 2007) and then, to clarify the role of self-propelledness in the comprehension of goal-directed actions, we investigated whether the self-propelledness was included in the behavioural or perceptual cues present in the scene-stimulus using by Biro and colleagues with twelve months old infants.

1. General Methods

Participants

Thirty-five healthy and full-term six-month-old infants were selected and recruited through mailing to participate in the study from the family register of Budapest (18 males and 17 females, mean age: 346,2 days, range: 334–364 days mean:11 months, 18 days). Eighteen additional infants were excluded from the final sample for the following reasons: some infants did not complete testing due to fussiness or drowsiness activeness, or inattentiveness, technical problems others were excluded as outliers because the total looking time in test phases differenced of ±2.5 Standard Deviations from the mean of fixation time.

Infants were tested only if awake and in an alert state after parents gave their informed consent.

Stimuli and Experimental Setting

The stimuli were computer-animated events involving three objects (a yellow circle, a red circle and a blue circle) and a column. The video-clips were shown on a high-resolution Samsung (Flat Panel 52'') computer monitor. The experimental apparatus was similar to the one used in previous experiments (Biro, Csibra and Gergely, 2007). The baby sat on their parent's lap in a darkened experimental room at a distance of about 70 cm from the monitor, the infant's eye level was at the centre of the screen. Above the monitor a video camera was mounted peeping through the opening of a black curtain, which allowed the experimenter to monitor the infant's eye fixations and to record the infants' eye movements for the off-line coding. The experimenter controlled the stimulus presentation and registered the looking times by operating a keyboard of a computer. To prevent interference from irrelevant distracters, plain dark curtains were drawn behind the monitor and on the room walls.

Procedure

After the infant was familiarized with the laboratory environment, he or she sat on the parents' lap in front of the stimulus monitor. The experiment was carried out using a visual habituation paradigm. At the beginning of each trial the experimenter drew the infant's attention to the display by showing colored flashes on the monitor. When the baby looked at the screen, the experimenter pressed a key which started the presentation of the habituation stimulus, then repeated continuously until the infant looked away for more than 2 seconds. When the infant looked away, the experimenter released the key on the keyboard, and if the operator did not press it again within 2 seconds indicating that the infant looked again towards the monitor, the computer program stopped the stimulus display and registered the looking time for the trial. When the infant looked at the screen again, the next trial was started. A trial had to last at least 2 seconds to be considered valid. The computer program calculated the average fixation time for the first three habituation trials and compared this value on-line with the running average of the last three fixation times. We used a habituation criterion which required that the average fixation time for the last three trials be less than half of the average looking times for the first three habituation trials. Thus, the minimal number of habituation trials was six. When the habituation criterion was reached, the stimulus was automatically turned off and a preference test phase started. The habituation with the stimulus action was followed by a preference test . The presentation order of the two test events was counter balanced across infants with half of them seeing the direct gaze condition first. Eye movement data were on line coded by an experimenter, blinded of the stimuli shown, who recorded the duration of the infants’ fixations on each stimulus by pressing a key. Moreover, videotapes of the infants' eye movements of the test phase were subsequently frame by frame coded by a second coder unaware of the stimuli presented (it was not possible for the coder to recognize the stimuli from the corneal reflection).

Data Analysis

Videotapes recordings of infant’s eye movements during the test events were analyzed frame by frame by two coders (an experimenter and a student); both coders were unaware of the kind of stimulus presented. The coders recorded, separately for each stimulus, the number of orienting responses and the total fixation time, that is to say, the sum of all fixations. Then the mean reliability between on-line and off-line coding was analyzed by Pearson Correlation, .

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

2. Experiment 1

We replicated the Biro and colleagues study to confirm that the stimuli and the experimental set were appropriate.

Participants

A total of fifteen twelve month old infants participated in the experiment 1 (9 males and 6 females), their postnatal mean age was: 359.62 days, (range: 334–364 days, mean: 11 months, 10 days). Eight additional infants were excluded from the final sample for the following reasons: 2 infants did not complete testing due to fussiness or drowsiness activeness, 2 for inattentiveness, 4 infants technical problems others were excluded as outliers because the total looking time in test phases differenced of ±2.5 Standard Deviations from the mean of fixation time.

Test stimuli

We used exactly the same stimuli as in the original work. In the habituation event a small red circle on the left side of the screen and a large blue circle on the right side of the screen appeared with a black rectangular column positioned in between them. The event started when a third yellow circle entered the screen horizontally from the left side and hit the small red circle. Upon contact the yellow circle stopped and the small red circle immediately started to move. The small red circle movement seemed as if launched by the impact of the yellow one. It then followed a parabolic pathway as if “flying over” the rectangular figure in the middle (the “obstacle”) and finally landed and stopped at the position adjacent to the large blue circle. The rectangular column appeared to form an “obstacle” separating the large circle and the small circle and its height was randomly varied over trials, being either small, medium, or large. The height of the small red circle parabolic pathway was always adjusted to optimally match the variable height of the ‘‘obstacle’’ in such a way that it always just managed to pass over it without colliding with it. During the two test events, the ‘‘obstacle’’ was no longer present. In the first test event, that we can call “Old Action” test event, the behaviours of the red and yellow circles were identical to those in the habituation event, it jumped to the other part of the scene with a path way corresponding to the medium height of its trajectory during the habituation events, but in absence of the obstacle. In the other test event, the “New Action” test event, however, the small red circle approached the blue circle with a novel pathway taking the shortest straight-line route that has now become available (Fig.17). The two test events were presented sequentially and the presentation was randomized between subjects. Every test event could be 60 sec long, but stopped automatically if infants looked away for more than 2 sec.

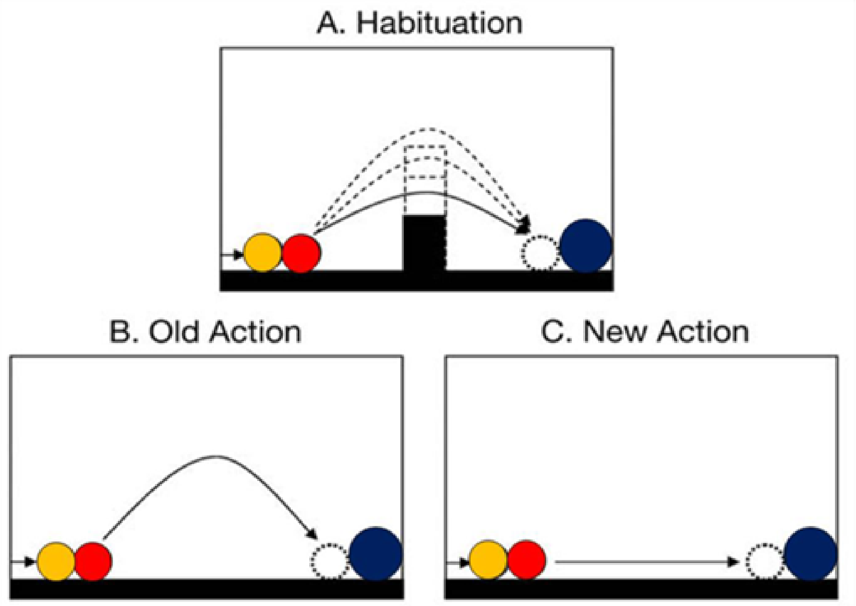

Fig.17 A schematic representation of the stimuli used by Biro and colleagues and replicated n the Experiment 1.

Results

The average number of completed habituation trials was 6.6. The average total fixation time was mean = 9783 sec for the Old Action test event and mean = 6707.7 sec for the New Action test event. The mean estimated reliability between on-line and off-line coding for 10% of the total participants was analyzed by Pearson correlation ($p = .001$). The infants looking time in the test events were analyzed by ANOVAs using event type (old vs. new) as a within-subject factor, and order (old first vs. new first) as a between-subject factor ($F_{(1,13)} = 9.46$, $p= .010$). Our results confirm the previous findings, indeed infants looked longer to the old action test event, as a response of a novelty for the inconsistent pathway of the yellow circle, just like in the original work. No order effect was found ($F_{(1,13)} = .003$, $p= .93$).

3. Experiment 2

The above mentioned findings of the previous replicating experiment can confirm that self-propulsion is not a necessary prerequisite for goal attribution and its absence does not necessary inhibit the interpretation of behaviours in terms of goal (Biro, Csibra and Gergely, 2007). As in the original study the only informational basis for goal-attribution in this experiment was provided by the consistent pattern of adjustments observable in the height of the trajectory performed by the object across trials that always optimally matched the variation in the height of the “obstacle”. These adjustments were justifiable because they ensured an efficient goal approach across the variable situational conditions. Thus, justifiable adjustment of goal approach in itself proved to be a sufficient cue for goal attribution. But, an alternative assumption is that the scene carried self-propelledness through behavioural and perceptual cues. In particular, we can speculate that the red circle, the one that actually jumped and performed the action was not self-propelled because it was moved from the yellow circle movement. Instead the yellow ball could be categorized from the infants as self-propelled because it entered the scene in an independent way. Then infants could interpret the yellow circle as the social object author of the action. So in this study we decided to investigate the role of the self-propelledness in the comprehension of an action in which inanimate objects are involved and in which self-propelledness movements are not clearly explicated. Differently from the previous task we introduced a spatial and temporal gap between the yellow and the red circle conferring the only possible role of intentional agent to the second one. Biro and colleagues described their scenes as goal directed actions, but an open question is if the role of the yellow ball has a fundamental implication in the action of the red ball. In order to be recognized as goal directed. We predicted that if the yellow circle role is fundamental for the action, in this case, the infants will not in test phases show a preference between the old and the new action. Otherwise if the red ball is recognized as the intentional one, and if it does not need the presence of the yellow circle to jump over the obstacle, we predicted that the infants would have looked longer to the old action as in the previous work (Biro et al., 2007).

Participants

Twenty twelve-months-old infants participated in this experiment 2 (9 males and 11 females, mean age: 345.74 days, range: 334–364 days mean: 11 months, 16 days). An additional ten infants were also tested but were excluded from the data analysis due to fussiness or short looking time in the test event. All of the subjects were healthy, full-term infants living in the Budapest area who were recruited through mailings.

Test stimuli

We used the same stimuli and habituation paradigm presented in the previous experiment. Differently from that task we introduced a spatial and temporal gap between the first and the second circle in the test events, conferring the role of intentional agent to the second one (the red circle) (Fig.18). In this experiment the event started when the yellow circle entered the screen horizontally from the left side and did not contact the small red circle, but stopped before touching the red circle. Then, after few seconds the small red circle started to move. The small red circle movement did not seem as if launched by the impact of the yellow one, but, in this case, the red circle started to move in an independent way. It followed a parabolic pathway as if “flying over” the rectangular figure in the middle (the “obstacle”) and then it landed and stopped at the position adjacent to the large blue circle as in the previous study. The test phases were also the same as the previous work with the new spatial and temporal gap between the red and the yellow circle.

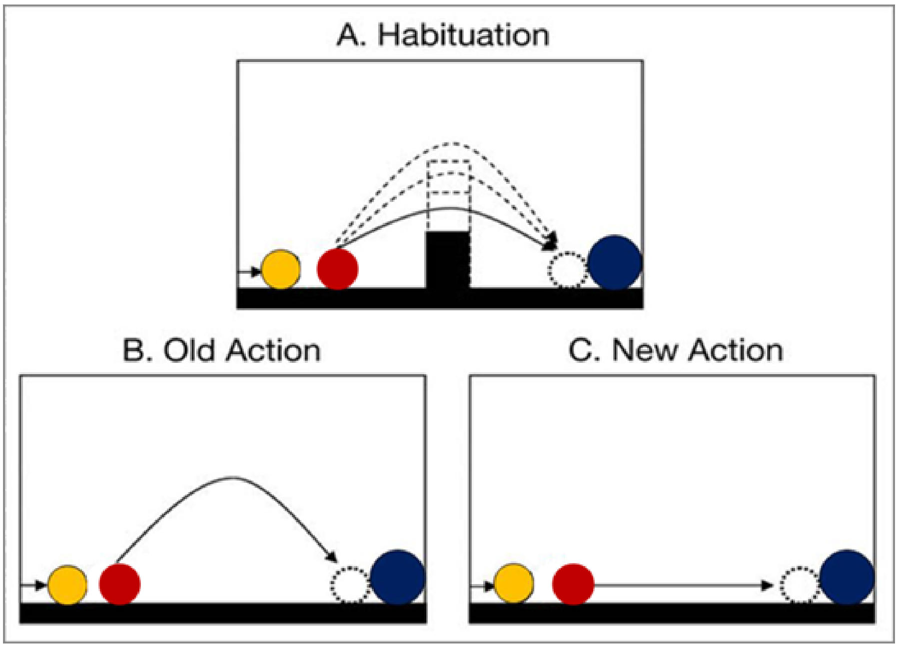

Fig.18 A schematic representation of the stimuli used in the Experiment 2.

Results

The average number of completed habituation trials was 7.05. The average total fixation time was mean = 8764 sec for the Old Action test event and mean = 11771 sec for the New Action test event. The mean estimated reliability between on-line and off-line coding for 10% of the total participants was analyzed by Pearson correlation (p = .001). We measured the looking time during the two test phases and they were analyzed by ANOVAs using event type (old vs. new) as a within-subject factor, and order (old first vs. new first) as a between-subject factor. The analysis did not reveal a main effect of event type ($F_{(1,18)}$ = .776, p = .390), indicating that the infants looked equally at the old action test event and at the new action test event. No effects of order were found ($F_{(1,18)}$ = .154, p = .699). These findings reveal that infants did not understand the goal of the action in the habituation event and therefore have not revealed differences in looking times in the two test events which seemed to be both different from the habituation event (Fig.19).

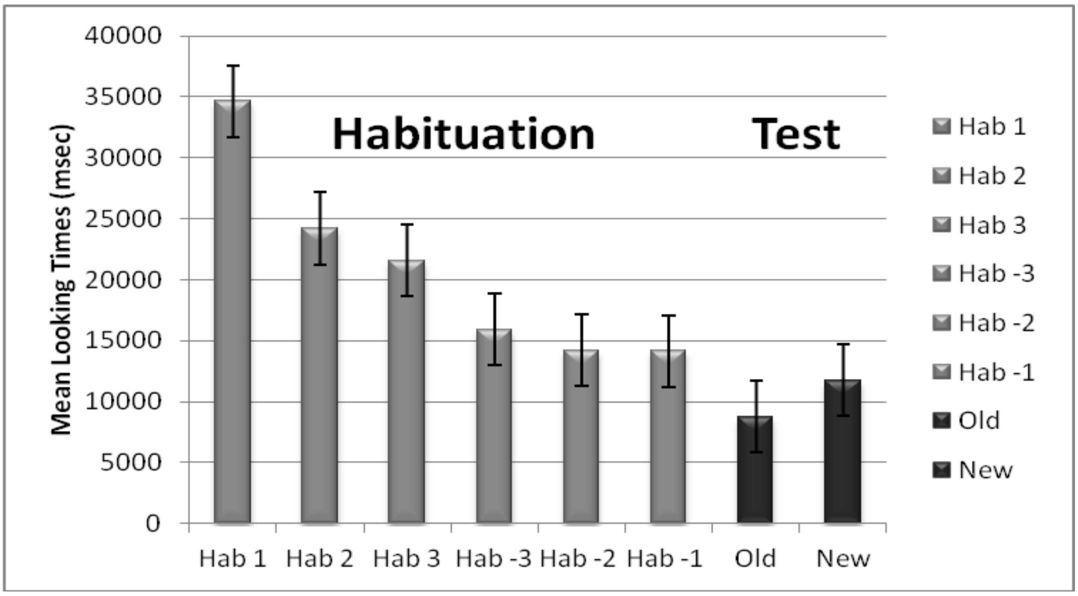

Fig.19 Average fixation time (msec) spent by the infants looking at the habituation event in the first six trials and the two test events.

4. Discussion

Confirming our hypothesis, behaviours of self-propelled objects are more likely to be interpreted in terms of goals than behaviours of non-self-propelled objects, especially in otherwise ambiguous events which lack any other behavioural cues (such as the contact between the two circles). For this reason I reasoned that in the previous work (Biro et al., 2007) the infants attribute the role of intentional agent to the first object (the yellow circle), the one that started the action and allowed the second one (the red circle) to jump beyond the obstacle. In our study the yellow object lost its characteristics (i.e. the capacity to initiate the action) and the test event become a non goal-directed action for twelve months old infants. We can suppose that the infants did not attribute goals to the yellow object because it did not touch the second circle, it entered the scene and it stopped its movement without any interaction with the second agent; furthermore the infants did not attribute goals to the second agent (the red circle) either, because it did not show any self-propelledness attribute and the consistent adjustments shown by the jumping ball at different heights was not a sufficient context cue without a communicative motion cue. One interpretation is that infants did not categorize the test event as intentional action because the available information did not clearly mark any object as a social object. So we can stress that the presence of an evident self-propelledness is necessary in order to communicate actions to be interpreted.

In this study the action looses it communicative function in absence of evident self-propelled movements but it is possible to speculate that the absence of a self-propelled movement can be substituted from other perceptual cues (i.e. the feature of the object). In this view it would be interesting to test the case in which the red circle (the one that jumps to the other part of the scene) ware a human like agent, like a puppet. In this case the scene could become intentional, because the features would be sufficient for infants to interpreted the action as goal directed and the self-proppelledness of the agent would not be necessary.

CHAPTER 5

EXPERIMENTAL RESEARCH

The Near Infrared Spectroscopy (NIRS) technique

The Near-Infrared Spectroscopy (NIRS) technique is a non invasive optical technique which provides the opportunity to measure hemodynamic responses to neural activation also in awake infants. In fact previous works investigated similar neural activation in adults using techniques such as fMRI, but brain activations have not been investigated with this technique during infancy because it is not fit to accommodate mobile, awake infants. In the NIRS the light migrates from sources on a sensor pad located on the head, through the skin, skull, and underlying brain tissue and it is then detected by sensitive detectors on the same sensor pad. Changes in blood oxyhemoglobin (HbO2), deoxyhemoglobin (HHb), and total hemoglobin (HbT = HbO2 + HHb) in the underlying cortex are measured by detecting changes in reflected near infrared light. The concentration of hemoglobin changes according to the metabolic demand of the neurons in a given cortical region. Often brain activations in infants were investigated using electroencephalography (EEG), event related potentials (ERPs), but the major advantage of NIRS compared with EEG is that it is less susceptible to data corruption by movement artefacts and offers a more highly spatially resolved image of activation, allowing the localization of brain responses to specific cortical regions. In addition, compared with fMRI, NIRS has a higher temporal resolution (a few milliseconds for NIRS compared to 1-2 seconds for fMRI), is silent, allowing easy presentation of auditory stimuli and can measure both oxy- and deoxy-haemoglobin chromophores (the molecules that are responsible for the colour of the blood due to their absorption of light at different wavelengths), providing a more complete measure of the haemodynamic response. Naturally, as with any technique there are also limiting factors of NIRS; the temporal resolution is lower than EEG (Luck, 2005); the depth resolution is dependent on the age of the infant and the optical properties of the tissue (see Fukui et al., 2003); the technique offers lower spatial resolution compared with fMRI; and there is no possibility of measuring brain structure for anatomical reference (see Minagawa-Kawai et al., 2008 for further discussion of these limitations). Furthermore the NIRS study presents another problem: the challenge of dealing with participants' hair. Firstly, hair reduces the grip of the headgear and probes on the head, secondly, the layering, differing orientation and colour of the hair lying between the probe and head causes attenuation of the light and can lead to unreliable measurements. If the hair is particularly dark the optical data may simply be unusable. In adult studies, a great deal of time is spent moving hair away from the area directly under the optodes. This is largely impractical with infants as they do not tolerate much interference of the hair/headgear before becoming fussy. In spite of this problem the NIRS investigation remains more useful with infants and newborns also because the skin, skull and the brain tissues are thinner and more translucent than in adults and so to reach the hemodynamic response is more direct

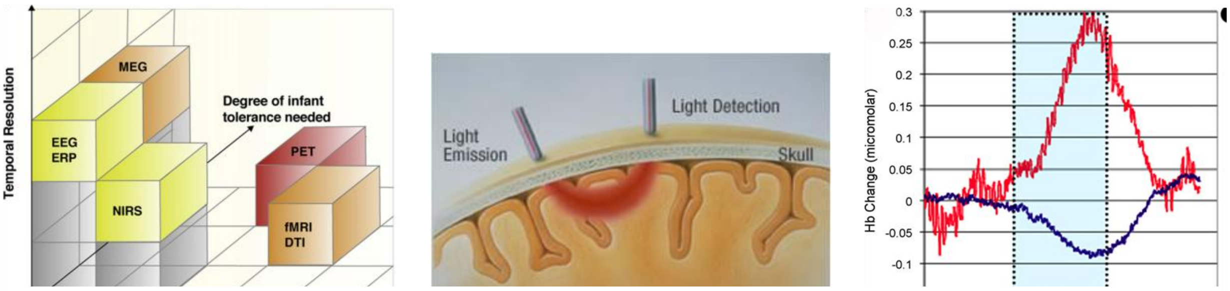

Fig. 20 (a) A schematic representation of the temporal and spatial resolution of neuro-imaging technique. (b) A typical course of the light in the cortex. (c) A typical hemodynamic response to cortical activation (increase in blood flow (in HbO2) and a (relatively smaller) decrease in HHb .

THE NEURAL BASIS OF THE EARLY PROCESSING OF COMMUNICATION IN EARLY INFANCY

1. Introduction

As it was described above in the first behavioural studies, biological motion perception is an important cue which contributes to the comprehension of communicative actions. Biological motion refers to the visual perception of a biological entities engaged in a recognizable activity. This definition includes the observation of humans walking and making eye, mouth and hand movements. People are highly adept to recognize biological motion, the movement of human or other animals. Moreover people are remarkably adept at recognizing the actions performed by others. In fact biological motion is integral to social perception which refers to the initial stages of evaluating the intentions of others using their gaze direction, body movements, hand gestures, facial expressions, and other biological-motion cues (Allison, Puce and McCarthy, 2000). A number of neuro-imaging studies have examined biological motion perception in the human brain. Areas identified in these studies includes the posterior superior temporal gyrus, the superior temporal sulcus (STS), the ventral temporal cortex (Grossman et al 2008; Saygin, Wilson, Hagler, Bates and Sereno., 2004; Allison et al., 2000). In particular in adults there are evidences that each social/biological motion evoked robust activation in the right posterior temporal-occipital cortex. There are evidences that the mouth movement's elicited activity along the middle-posterior STS while eye movement's elicited activity in more superior and posterior portions of the right posterior STS region. Hand movements activated more inferior and posterior portions of the STS region within the posterior continuing branch of the STS. Hand-evoked activity also extended into the inferior temporal, middle occipital and lingual gyro (Pelphrey, Morris, Michelich, Allison and Mc Carthy, 2005). One open question is how specialized is the infant brain, at birth and in the first months of life, for perceiving facial and manual movements displayed by others. From an early age, our brains selectively respond to biologically relevant movements, and further, selective patterns of region specification to different cues occur within what may correspond to a developing "social brain" network. These findings illuminate undocumented maps of selective cortical activation to biological motion processing in the early postnatal development of the human brain. As a support of the early specialization of the human brain, Lloyd-fox and colleagues (2009) investigated the functional activation in the social brain network in five-month-old infants using Near-Infrared Spectroscopy (NIRS) technique. This study investigated whether young infants show a hemodynamic response over the posterior temporal lobe, in the Superior Temporal Sulcus region, in response to a complex social stimulus involving biological motion. In this study the infants sat on their parent‟s lap and watched the stimuli (video clip) on a plasma screen. The experimental condition consisted in full-colour, life-size social video clips of female actors who either moved their eyes left or right, their mouth in silent vowel movements, or performed hand games "peek-a-boo". A full-colour images of different type of transports (cars or helicopters) presented randomly and occurring between each experimental trial were used as a baseline condition. These images were selected to be colourful, complex, and interesting, and ensured that infants remained attentive to the screen. The experimental trials and baseline trials were presented consecutively three times each. The results of the study revealed a significant increase from baseline in oxyhemoglobin in two channels located in the posterior area of the pads in response to the social dynamic stimulus. The activation corresponds at the T5 and T6 (10-20 system) locations that is consistent with the adults result reported from fMRI studies (Allison et al., 2000). The findings support the idea that 5 months old infants have a specialized area activated for the processing of social stimuli. However an alternative possibility is that the posterior response is attributed to MT, a motion sensitive area located near STS. It would be possible because the social dynamic stimuli and the baseline differ in the nature of the stimuli and in the dynamic motion. For this reason Lloyd-Fox and colleagues introduced in a second experiment non-social dynamic video clips of machine cogs and pistons and moving mechanical toys. These stimuli were selected because they involved complex, interacting curvilinear motion patterns that served as a good control for the social stimuli (biological and facial motion). In this case the social and the non-social video were presented sequentially with the baseline trials occurring between each experimental trial. The data analysis shows that the infants have a significant increase in oxyhemoglobin in response to the biological dynamic stimuli (the face of the female actor) located in the temporal regions replicating the results obtained in the experiment 1. The non-social stimuli did not reveal any significant changes in oxyemoglobin in the posterior area. Further, comparing the response for the social stimuli with the response for the non-social stimuli, a significant difference was found in the bilateral posterior channel. The social dynamic stimuli had a greater increase in oxiemoglobin compared with non social stimuli in posterior channel located in T5 and T6, the same area of the experiment 1. A significant increase in HbO2 was also found in the right anterior channels in response to the non-biological dynamic stimuli but also in biological dynamic stimuli, indicating a more general response property. In conclusion these findings provide further support for the hypothesis that infants as young as 5 months of age have a specialized area of the temporal cortex activated by dynamic social stimuli. The location of this neural activity in the temporal areas identified by the significant hemodynamic changes is consistent with the findings of studies on STS activity in adults in response to social stimuli.

2. Experiment

To investigate the development of the social brain structures in the first months of live I decided to use social and non social dynamic stimuli which involved an intentional action without the presence of the special stimulus face as in previous work (Lloyd et al., 2009) I assessed the hemodynamic response in cortical areas in five months old infants (to compare the results with Lloyd and colleagues evidences) using the same paradigm, technique and baseline stimuli of Lloyd and colleagues (2009) and involving as social dynamic stimuli the arm action used in the familiarization event in behavioural experiments (experiment 3) described in the chapter 4 and as non biological dynamic stimulus the non-biological tool action used in the familiarization event in behavioural experiments (experiment 4) described in the same chapter.

Participants

Eighteen healthy and full-term five-months-old infants were selected to participate in the study from the family register of Padua (8 males and 10females, mean age: 158 days, range: 147–16,1 days mean: 5 months, 8 days). Ten additional infants were excluded from the final sample for the following reasons: 5 infants did not complete testing due to fussiness or drowsiness activeness, 3 for inattentiveness, observer difficulties, 2 for technical problems with data collection.

Infants were tested only if awake and in an alert state after parents gave their informed consent.

Stimuli and Experimental Setting

It was used a visual stimulation paradigm adopted from a previous NIRS study with five-month-old infants (Lylod-Fox et al, 2009). The experimental condition consisted in full-colour, approximately life-size social video clips. In the experimental condition 1 a social biological stimulus was used, the video performed an object (a red ball) in the scene, then a hand entered in the scene and reached for and grasped the object. In the experimental condition 2 a non-social biological stimulus was used, the video performed a red ball in the scene, then a tool, which moved in a mechanical way as in the previous behavioral experiment (study 1,Exp 5) entered in the scene and reached for and grasped the object. A full-colour images of different type of transports (i.e. cars or helicopters) presented randomly for 10 seconds with each image presented for a pseudo-random duration (1 – 3 seconds) and occurring between each experimental trial were used as a baseline condition. These images were selected to be colorful, complex, and interesting, and ensured that infants remained attentive to the screen (Fig.21). The experimental trials and baseline trials were presented consecutively and the stimulation paradigm continued on a cyclical loop of presentation (social stimulus-baseline-non-social stimulus, 10 seconds for each trial) until the infants became tired or fussy (the average length of the presentation was three minutes). The overall surface area of the displayed experimental stimuli and baseline stimuli were equivalent. Note that fNIRS studies with adults use a blank screen as the baseline but this is not possible when working with infants, therefore the static images act as the baseline for the activated experimental period containing the human action video clips.

The study was conducted at the university of Padua. The infants sat on an experimenter's lap and were encouraged to watch the stimuli displayed on a 26-inch screen with a viewing distance of approximately 30cm. The infant's eye level was at the centre of the screen. Above the monitor, a video camera recorded the infants' eye movements to monitor their looking behavior online and to allow off-line coding of their fixations. To prevent interference from irrelevant distracters, plain blue curtains were drawn in behind the monitor.

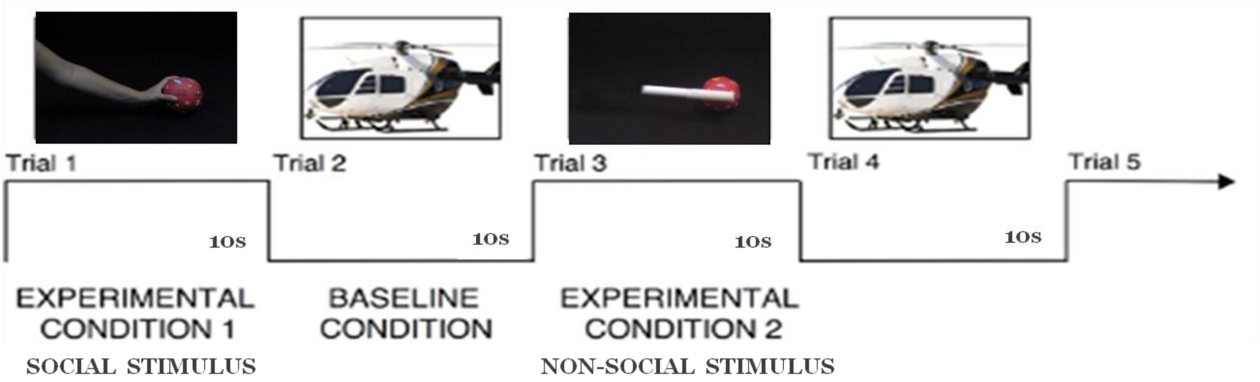

Fig. 21 A schematic representation of the experimental procedure. In the condition 1 it is showed the social stimulus, in the condition 2 the non-social stimulus and in the baseline it is shown an example of the different type of transports

Procedure and Data Analysis

To investigate cortical activation, NIRS measurements were made using a commercial frequency-domain oximeter (Imagent, ISS Inc.). The Imagent system is equipped with 16 sources (32 laser sources, 16 at 690nm, 16 at 830nm) and 4 photomultiplier tube detectors. The source light of the system is modulated at 110 MHz while the detectors are modulated at 110 MHz plus 5 kHz for heterodyne detection. The lasers of each source are time-multiplexed during measures. The light power emitted by the lasers at the fibre end is <4 mW/cm2, within the ANSI standard limits and permitting safe measurements. The sample rate was set to 16 Hz in order to obtain a good signal to noise ratio. DC and AC attenuations and phase shifts of the modulated light through the tissue were recorded. The optical source fibre and detection bundles were arranged in two flexible rubber probes, which were fixed to the head through a custom-built helmet. Source-detector distance was set to 1.8 cm, and 10 channels (couple source-detector) were configured for each hemisphere (Fig. 21 and Fig. 22). The set source-detector separation is adequate for the population investigated (Franceschini, Fantini, Paunescu, Maier, and Gratton, 1998; Fabbri, Sassaroli, Henry & Fantini, 2004; Fox, Blasi & Elwell, 2010) Before the infants' began the study, measurements of their head circumference, and distance between glabella, ears and inion were taken and the location of the channels and probes relative to these anatomical landmarks were recorded. Each probe was placed on the temporal region, with the midpoint at a fixed distance of 6cm from the centre of the forehead, aligned approximately with T3/T4 of the 10-20 system on the average newborn head (17 infants; median cranial circumference: 34.5 ± 1.4cm). The posterior half of each probe lies approximately over the scalp locations T5/T6, analogous to the region of interest (Lylod-Fox et al, 2009).

Data processing and analysis.

Fast Fourier Transform of the signal was performed to compute the AC component (amplitude), DC component (average Continuous Wave "CW" intensity) and phase shift of the waveform signal from the 20 channels. The concentration changes were assessed using the modified Lambert Beer law (Delpy, Cope, van der Zee, Arridge, Wray, and Wyatt, 1988) with a predicted Differential Pathlength Factor (DPF) .The data were band-pass filtered (0.04-0.5 Hz, FIR digital filter) to attenuate slow drifts and high frequency noise, mainly caused by physiological noise such as respiration and heart rate. Movement artifacts, were corrected by a semi-automated procedure, which allowed artifacts to be marked within single channels then the contaminated data segments were corrected by linear interpolation (Grossmann & Johnson, 2010; Koch, Steinbrink, Villringer & Obrig, 2006; Wartenburger, Steinbrink, Telkemeyer, Friedrich, Friederici & Obrig, 2007). For each infant we recorded data from 4 to 7 full responses to each sequence. The neural activity in response to the social and non-social stimuli respect to the baseline was modelled as a square-wave function lasting 10 seconds. This covariate was convolved with a hemodynamic response function (HRF) and compared to the filtered HbO2 concentration changes to yield appropriate predictors (beta values). This was done in a generalized linear model (GLM) and in analogy with fMRI analysis.

We used adult HRF because of lack in literature of studies on such young children and the substantially invariance of the statistical results with changes in HRF of the magnitude of the ones reported on older children. The mean square deviation between the model and filtered HbO2 concentration changes was evaluated. Trials with channels that showed deviation within the population ≥ 99% percentile were disregarded. The rejection rate for stimuli was 7% on average, with a maximum of two disregarded responses of the same stimulus in one newborn. Statistical analysis was performed on beta values of HbO2 concentration changes. We evaluated the average response for each channel weighted on the number of received stimulus trials for each infant. A t-test analysis evaluated statistical significance of the average activation/deactivation within each channel (activation/deactivation defined as a significant increase/decrease in HbO2). The standard deviation of the maximum displacement (half head circumference) among newborns, measured from the centre of the forehead assumed as reference point, was estimated as low as 0.7 cm, in comparison with a source-detector distance (that is the order of magnitude of spatial sensitivity) set to 1.8 cm. The analysis of activation/deactivation within each channel among different children should be considered significant when the inter-fibre distance is larger than the standard deviation of cranial circumferences. Two Regions of Interest (ROIs) were identified for each hemisphere: fronto-temporal (FT) and temporo-occipital (TO). Three-way (stimulus: social vs. non-social; hemisphere: right vs. left; region: FT vs. TO) multivariate ANOVA was performed on beta values dataset for each channel response. Statistical significance p-value was set to 0.05. A two dimensional topographic image was reconstructed, considering the spatial sensitivity profile in reflectance geometry (Carraresi, Shatir, Martelli & Zaccanti, 2001)

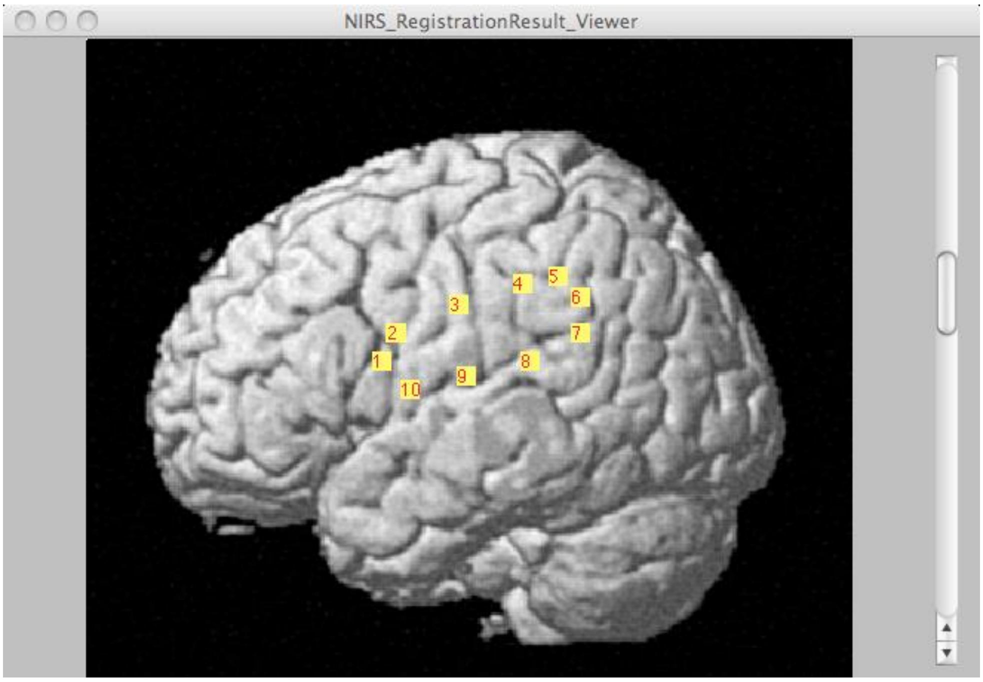

Fig. 21 A schematic representation of the channels disposition in the lest temporal regions

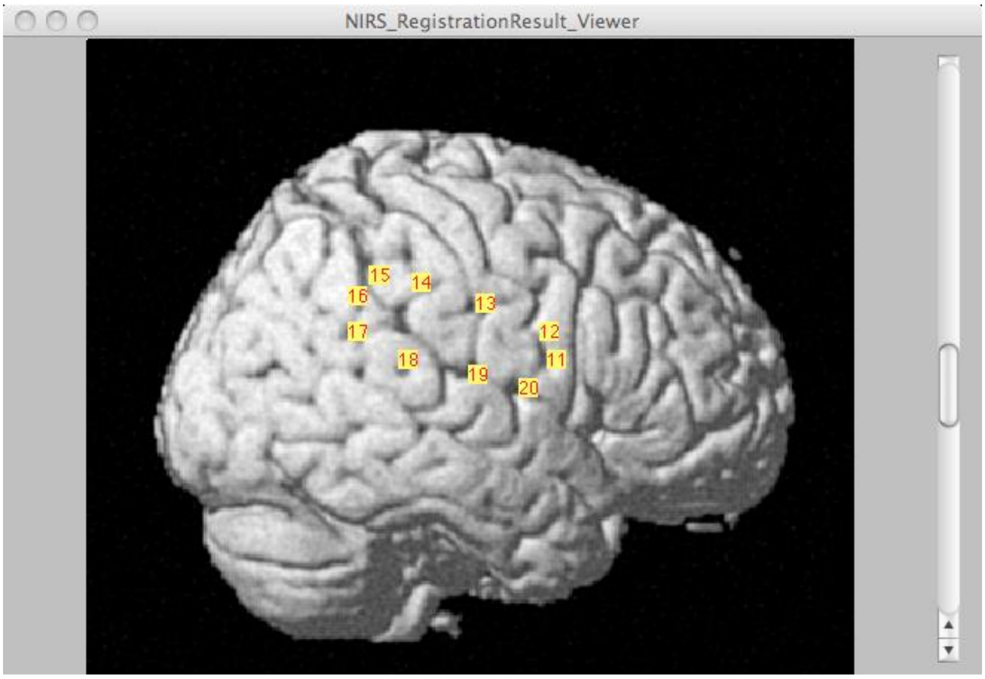

Fig. 22 A schematic representation of the channels disposition in the right temporal regions

Fig. 23 A photo of the infants with the probe

Result and Discussion

Infants were shown two experimental conditions of visual and naturalistic dynamic social stimuli (such as an arm which reached for and grasped an object) and dynamic non-social mechanical stimuli (such as toll which reached for and grasped an object with a mechanical motion), and a baseline condition consisting of naturalistic static non-social stimuli (photos of vehicles). The NIRS headgear was placed on the infant's head and changes in oxy-haemoglobin (HbO2) and deoxy-haemoglobin (HHb) concentration (µmol) were calculated relative to baseline and used as haemodynamic indicators of neural activity. Multivariate ANOVA indicated significant effects of Stimulus (F=19.63, p=.0001), the interaction between Region-of-Interest ROI (fronto-temporal and temporo-occipital) and hemisphere (F=5.03, p=.0319), but interaction between Region-of-Interest ROI, hemisphere and Stimulus (F=4.99, p=.0327). The statistical analysis of HbO2 signals and beta values using t-tests showed relevant activation to the social stimulus in channel 16 ($t_{(17)}$=2.11, p= .049) and channel 17 ($t_{(17)}$=3.08, p=.006) and to non social stimulus in channel 16 ($t_{(17)}$ = 2.66, p= .016). No significant HHb changes were found. A paired-sample t-test in the channel 16 activated either in response to social and non social stimulus revealed a significant difference in the activation of the channel in response to social stimuli ($t_{(17)}$=2.02, p=.05). Even if channel 17 was not activated in response to non social stimuli, the same statistical analysis was used for the mean of channel 16 and 17 in the two condition because the near location of channels and the paired t-test revealed a more activation in that area in response to social stimuli ($t_{(17)}$=2.47, p=.02).

The reconstructed topographic image of the HbO2 concentration changes, suggested posterior activation for the social stimulus. T-test outcomes for the HbO2 signal on channel 16 and 17 showed that the activation in the right posterior area was greater than in the left posterior area. This result suggest that the significant response in the channels was in a similar region to that found in the five month old infants with social stimuli involving face biological moments.

So, this neuroimaging data show that brain regions in the posterior temporal region and in particular the region localised near the superior temporal sulcus are involved in the process of social communicative action and are activated in response of dynamic social stimuli involving biological cues (i.e. the perceptual features and the kind of motion) in five months old. Moreover this results are compared with the evidence of previous work which suggest that, in the first months of life, the temporal region seem to have a progressive specialization in the processing of social dynamic stimuli (Lylod-Fox et al., 2009). These data are also similar to the findings showed by neuroimaging studies with adults (Allison et al., 2000). The results of this neuroimaging investigation suggest a relatively early functioning of the cortical structures involved in perceiving other humans actions just in infancy. Even if this functioning may be broadly tuned, and less specialized, than that seen in adults, but having this network at least partially functional early in life may point to the pivotal role that social communication and learning plays in human development

CHAPTER 6

GENERAL DISCUSSION

In the last years one of the most studied aspects of the social cognition development is the perception of others as intentional agents. The social brain and the human capacity to elaborate social information allow people to see others’ actions not just as a physical movement, but as a movement organized by intentional relations between the agents and their objects of attention. In the neurocostrutivism prospective the role of the human experience and the maturation of brain structure are considered as fundamental to human social cognitive development. The abilities with which infants are born and the mechanisms by which they acquire the knowledge of the physical and social world and whether and how adulthood specialization develops are determined as a function of development, the experience and their interaction. In this view one central issue is to understand how cognition grows and which changed and modifications allow to reach adults' specialization. In this work the nature of communicative action interpretation in infancy was investigated as one of the fundamental abilities of the social knowledge in infants. The role of the motion and its correlation with features cues was tested using behavioural and neuro-imaging paradigms. The overall results about the comprehension of communicative actions can confirm previous evidences which claimed that infants can understand an intentional action not only when the agent is a biological actor, like an human hand, but also when the agent is an inanimate object and seems to move in an independent way. In particular in this studies it was investigated the hypothesis that the motion has an important role in the comprehension of the intentional action. It seems that the kind of the motion (i.e. biological or non-biological motion) and its interaction with the agent's features (human or inanimate) could interfere in the attribution of the intentionality in early infancy. The behavioural results revealed that different kinds of motion can modify the interpretation of goal directed actions. The presence of a biological motion is a main cue which allow six months old infants to categorise an object as a social one. Therefore infants expect the social object to act in a communicative way. This communication ability of the actions vanishes when there is not a possible choice in the actions. The presence of a biological motion in these conditions seems not to be sufficiently informative for the infants to understand the intentionality in absence of a choice in the presented action between two possible goal-objects (Woodward, 1998; Biro and Leslie, 2007), actually in this situation the biological movement makes less salient the fact that the action is goal directed. This evidence confirmed that the presence of a choice is a discriminating characteristic to give a communicative role to the action, in its absence the action is just an action without any intentional and communicative role. As a matter of fact the natural-biological movement invests the actor of an intentionality that is not expressed by the action in the absence of two possible goal-objects. Contrary, the presence of a non-biological motion allow infants to understand the scene as an intentional one even if only one goal-object is presented in the scene. The use of a mechanical motion does not give the expectation that the tool can act in a communicative way and do not attribute self-intentionality to the agent. This could attract the infants because of the inconsistency of therefore to pay more attention to the scene and process the action as goal-directed, attributing the intentionality to the agent after watching the complete action. Moreover the behaviours of self-propelled objects are more likely to be interpreted in terms of goals than behaviours of non-self-propelled objects, especially in otherwise ambiguous events which lack any other behavioural cues. In general it is possible to suppose that an action looses its communicative function in absence of evident self-propelled movements and that the characteristics of the motion are the main communicative cues interpreted by infants to categorise the objects and to interpret communicative actions. In conclusion this work suggest that infants possess sophisticated expectations about physical and social events. It seems that they possess specialized structure to acquire their physical and social knowledge and for the formation of objects categories; infants distinguish and process objects between social and non social using behavioral and perceptual cues (i.e. the biological and self-propelled movement) and they reason and learn in terms of these categories. For this reason, for example, they expect that an objects which show a biological and self-propelled motion act in a different way in contrast with inanimate object which move in a non-biological way, and they expect an execution of intentional action only from the first categories of objects.

This behavioural evidence are supported also by neuroimaging studies (NIRS study). Neuroimaging data show that brain regions in the temporal cortex and in particular the region near the superior temporal sulcus are involved in the process of social interaction and are activated in response of dynamic social stimuli in five months old. Moreover it seems that during the first months of life this temporal region has a progressive specialization in the processing of social dynamic stimuli as it is described in previous work (Lylod-Fox et al., 2009). These findings support the view that structures in the social brain network initially have more homogeneous response properties, with common processing of many aspects of faces, bodies and actions. With experience, these structures may become more differentiated and specialized in their response properties, finally resulting in the specialized patterns of activation typically observed in adults. In adults this region is activated when people observe someone moving their eyes (Pelphrey et al. 2005) and this activity is modulated by the context in which the eye movement occurs, its activity is elicited if the observed actor moves his eyes away from, rather than towards, a flashing target (Pelphrey Viola & McCarthy, 2004) and similar effects are elicited also by movement of the mouth, hand or bodies (Pelphrey, Morris, Michelich, Allison & McCarthy, 2005). From infant neuroimaging data, it is possible to see some similarities between how the adult and infant brains process social information. These data suggest a relatively early functioning of the cortical structures involved in perceiving other humans just in infancy. However, this functioning may be broadly tuned, and less specialized, than that seen in adults. Having this network at least partially functional early in life may point to the pivotal role that social communication and learning plays in human development. In conclusion my findings seem to suggest that an interaction between the experience and the natural predispositions of the brain structural is at the basis of the social development. It seems that the human postnatal functional brain development is not just a passive maturational sequence, but is an activity processes mediate by experience and guides by initial predispositions. Moreover this view has implications for atypical development in that some developmental disorders, such as autism, that involve disruption to the social brain networkmay be characterized in terms of failures or delays of the specialization of structures on the cortical social brain network (Johnson, 2005). For this reason to investigate early predictors of atypical development of the social brain future researches are needed to examine the neural correlates of these more complex aspects of social cognitive development and to test the perception of social stimuli also in risk population.

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