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Detection of Social Agents: The role of kinematic cues

Thesis written with the financial contribution of University of Padova

Coordinator: Prof. Giovanni Galfano

Supervisor: Prof. Francesca Simion

Co-Supervisor: Prof. Paola Sessa

Ph.D. student: Marco Lunghi

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Riassunto

Una delle domande di ricerca più affascinanti all'interno delle scienze cognitive dello sviluppo riguarda il comprendere a quali cambiamenti la cognizione vada incontro nel corso dello sviluppo per raggiungere il livello di specializzazione osservato nell'adulto. A tal fine, una delle più grandi sfide è quella di determinare quali siano le abilità che i neonati posseggono fin dalla nascita e come le predisposizioni innate fungano da innesco nel processo di specializzazione del sistema nel corso dello sviluppo e in funzione dell'esperienza. In particolare l'obiettivo di questo lavoro è quello di studiare come il sistema si specializzi per riconoscere degli agenti sociali considerando il fatto che gli esseri umani sono creature sociali in grado di comprendere le intenzioni e le emozioni altrui basandosi sulla analisi di segnali non verbali e che nell'adulto è presente una specializzazione neurale e funzionale per l'elaborazione di stimoli sociali (Adolphs, 2009). Riconoscere gli agenti sociali implica la messa in atto di una serie di processi, quali orientare l'attenzione verso di essi, saperli discriminare rispetto ad altri stimoli, quali ad esempio gli oggetti inanimati, e poterli categorizzare come agenti sociali, che si affinano man mano nel corso dello sviluppo. Sicuramente, in ottica evolutiva, l'abilità di poter utilizzare il movimento come indice per poter riconoscere e categorizzare un agente come sociale potrebbe essere un precursore fondamentale di abilità cognitive più sofisticate, quali anticipare l'obiettivo delle azioni altrui e di conseguenza adeguare il proprio comportamento (Gallese, Rochat, Cossu, & Sinigaglia, 2009). Non ci sono dubbi infatti, che prima di attribuire obiettivi e intenzioni agli altri, gli esseri umani individuino gli altri esseri sociali nell'ambiente e che, per poter fare questo, abbiano

bisogno di usare indici percettivi che consentano loro di discriminare tra esseri animati ed inanimati.

Considerando il movimento come un aspetto fondamentale che gli esseri umani possono utilizzare per distinguere gli essere animati dagli inanimati e riferendomi al modello teorico del Neo/Neuro-Costruttivismo, l'obiettivo della mia tesi di dottorato è quello di testare il ruolo svolto dagli indici di movimento nella identificazione degli esseri sociali e delle loro azioni.

In particolare, la mia ipotesi è che il nostro sistema visivo abbia fin dalla nascita dei biases attentivi per dei specifici indici di movimento che caratterizzano il movimento degli esseri animati. Questi biases sarebbero i punti di partenza da cui origina il cervello sociale che a partire dalla identificazione degli esseri viventi arriverà "a leggere" non solo gli obiettivi delle azioni ma anche le intenzioni e gli stati mentali degli altri esseri sociali. L'esperienza avrebbe dunque un ruolo centrale nello strutturare il sistema e nel farlo diventare specializzato ad elaborare le informazioni sociali.

In quest'ottica, nel primo capitolo di carattere teorico, verrà introdotto l'approccio Neo/Neuro-costruttivista e verrà descritto come il cervello sociale e la cognizione sociale si sviluppano nella specie umana.

Nella seconda parte della tesi (Capitolo 2). saranno presentati una serie di esperimenti il cui obiettivo sarà quello di testare l'ipotesi che fin dalla nascita il sistema abbia dei biases attentivi verso gli indici cinematici che caratterizzano il movimento degli esseri animati. Impiegando paradigmi quali la preferenza visiva e l'abituazione, è stato investigato a quali indici di movimento, che nell'adulto elicitano la percezione di un oggetto come animato, il sistema visivo fosse sensibile fin dalla nascita. Nello specifico i neonati hanno mostrato di preferire il movimento auto-generato rispetto ad un inizio di movimento ambiguo (Esperimento 1 e 2).

I risultati degli Esperimenti 3, 4, 5 e 6 dimostrano, come fin dalla nascita il sistema umano possieda un bias attentivo per un oggetto che cambia velocità con una sequenza caratterizzata da accelerazione-decelerazione rispetto ad un oggetto che si muove a velocità costante, ma solamente quando i cambi di velocità in accelerazione e decelerazione sono presentati insieme e nell'ordine in cui l'accelerazione preceda la decelerazione.

Questi risultati confermano la presenza di bias attentivi per gli indici di movimento che caratterizzano gli esseri animati. Quest'iniziale predisposizione permetterebbe al sistema di focalizzare l'attenzione verso indici di movimento quali, il movimento auto-generato e cinematiche caratterizzate da cambi di velocità in termini di accelerazione e decelerazione, anche quando questi indici sono presenti in configurazioni complesse di punti come dimostrano le ricerche che attestano una preferenza per il movimento biologico alla nascita (Simion, Regolin, & Bulf, 2008; Bardi, Regolin, & Simion 2011). Studi condotti con adulti hanno inoltre dimostrato che da queste configurazioni di punti è possibile estrarre una serie di informazioni socialmente rilevanti come ad esempio il genere e lo stato emotivo (Kozlowski & Cutting, 1977; Dittrich, Troscianko, Lea & Morgan 1996) e che la direzione della camminata determina un orientamento dell'attenzione verso la direzione dello spazio da essa indicata (Bardi, Di Giorgio, Lunghi, Troje & Simion, 2015). In quest'ottica, l'obiettivo degli esperimenti descritti nel Capitolo 3, è stato quello di testare se la direzione della camminata umana veicolata da un insieme complesso di punti possa elicitare un orientamento attentivo anche nei bambini di pochi mesi di vita. A tal fine è stato utilizzato il paradigma di *cueing* (Posner, 1980) e sono state registrate le risposte evento relate alla comparsa di uno stimolo periferico (ERPs; HD Geodesic System). I risultati degli Esperimenti 7 e 8 dimostrano che l'abilità di poter utilizzare la direzione della camminata come indice per orientare l'attenzione compare a partire dai 6 mesi di vita.

I dati elettroencefalografici dimostrano che sia nei bambini di 6 mesi di vita che in partecipanti adulti, l'orientamento attentivo veicolato dalla direzione della camminata umana produce un effetto sulle componenti sensoriali quando uno stimolo periferico compare nella posizione spaziale indicata dalla direzione della camminata umana (Esperimenti 8 e 9). La modulazione delle componenti sensoriali sembra suggerire che la direzione della camminata umana eliciti un orientamento attentivo e di conseguenza produca un "beneficio" in termini di miglior elaborazione delle informazioni che compaiono in posizioni congruenti alla direzione della camminata.

Complessivamente, i dati presentati in questa tesi estendono le precedenti conoscenze che dimostravano che la detezione degli agenti sociali si basa sulla presenza della configurazione volto (Valenza, Simion, Macchi Cassia & Umiltà, 1996) e mostrano che essa avviene anche sulla base di indici di movimento a cui il nostro sistema visivo è sensibile fin dalla nascita. Questo avvalora l'ipotesi che la presenza di biases attentivi verso alcuni peculiari indici cinematici focalizzi l'attenzione su queste informazioni rilevanti e filtri l'esperienza che il sistema umano acquisisce per la costruzione del cervello sociale. In quest'ottica i biases attentivi e l'esperienza sono il punto di partenza su cui il sistema si specializza nel riconoscimento degli agenti sociali e su cui poi la specie umana costruisce la cognizione sociale. Queste conclusioni sono in linea con l'approccio Neo/Neuro-costruttivista e suggeriscono che l'esperienza con i conspecifici svolga un ruolo rilevante durante lo sviluppo per strutturare la conoscenza e determinare la specializzazione del sistema.

Abstract

A central issue in developmental cognitive science is to understand how cognition develops and changes over time to reach an adult level of specialization. Determining the abilities with which infants come equipped into the world, their mechanisms for acquiring knowledge, and whether and how these abilities change as a function of development and experience is a challenging issue.

Since humans are intensely social creatures and they tend to rely on visual signals for communicating psychological dispositions, intentions and emotions, the study of how our system becomes specialized to detect and recognize others is an interesting field of research. A fundamental human social ability is the capacity to accurately detect and understand the intentional conduct of others, to anticipate their upcoming actions, and to appropriately adjust their own behavior (Gallese, Rochat, Cossu, & Sinigaglia, 2009). Particularly, face and body motion represent primary social cues and it has been demonstrated that adults' brain has a specific neural network that supports detection and recognition of conspecifics and their actions (Adolphs, 2009).

From an ontogenetic perspective, the ability to read behavioral cues may be regarded as the fundamental precursors of more sophisticated social cognitive abilities (Gallese et al., 2009). Indeed, there is no doubt that before attributing goals, desires, dispositions to social agents, humans need to detect them in the environment and they need to use perceptual cues that allow them to discriminate animate *versus* inanimate objects. One of the most powerful cues that attract attention since birth is motion. Moreover, motion of living being has specific features that are not shared with motion of inanimate objects.

Considering motion as a fundamental feature that human species might use to detect others and within the Neo/Neuro-constructivist theoretical framework, the purpose of my PhD dissertation is to test the role of kinematic cues in detection of social agents.

Particularly, my hypothesis is that our visual system, since birth, possesses some attentional biases towards specific cues of motion that characterize animate entities. These low-level biases are the building blocks, on which during development, infants built their ability to infer other intentions. In this vein, the experience during the first months of life, plays a central role in shaping how our species can use kinematics information, and also in shaping the system to become specialized in processing social information.

With this consideration in mind, my thesis begins with a theoretical chapter describing the Neo/Neuro-constructivist approach and how it explains the origin of social brain and social cognition in humans.

Subsequently, in the second part of the thesis I will describe a series of experiments aimed at testing the hypothesis of the presence of low-level attentional biases towards cues of motion that characterize human motion since birth (Chapter 2).

Using both the visual preference and the visual habituation techniques, the aim of the experiments presented in Chapter 2 was to investigate to which motion cues that in adults elicit animacy perception, the human visual system is sensitive since birth. On the basis of previous evidence showing that human infants, adults and even newly hatched chicks seem to use dynamic cues such as self-propulsion, change in direction, (Mascalzoni, Regolin & Vallortigara, 2010) and speed changes to discriminate between animate and inanimate entities (Tremoulet & Feldman, 2000; Lou & Baillargeron 2005) human newborns without any previous experience have been tested, (Experiment 1; Experiment 2). Collected data demonstrate that at birth also human newborns are sensitive to these cues.

Furthermore, results from Experiment 3, 4, 5, and 6, demonstrate that newborns possess an innate predisposition towards a specific acceleration-deceleration pattern of kinematic (Experiment 5), and they do not manifest any preference towards a single speed change (Experiment 3, and 4) or when the order of presentation of acceleration-deceleration is inverted (Experiment 6).

These results have been interpreted as suggesting that newborns possess some attentional biases towards cues of motion that characterize animate entities. This inborn sensitivity towards self-propulsion and acceleration-deceleration pattern of motion allows the system to focus attention towards these specific cues of motion also when they are embedded in complex arrays.

Previous evidence demonstrates that newborns and infants manifest a sensitivity toward these motion cues also when they are embedded in a complex array of dots (i.e. Simion, Regolin & Bulf, 2008; Bardi, Regolin & Simion, 2011). Moreover, evidence collected with adults demonstrates that when the complex array of dots depicts a walking human figure, adults can retrieve multiple information form it such as walking direction (Bardi, Di Giorgio, Lunghi, Troje & Simion 2015). In light of this, the aim of the experiments described in Chapter 3, was to test whether the information of directionality conveyed by a complex array of dots can trigger orienting of attention in infancy. Specifically, a cueing paradigm was employed (Posner, 1980) and target locked event related responses (ERPs; HD Geodesic System) were recorded. Data from

Experiments 7, and 8 demonstrated that the ability to use walking direction to orient attention towards the peripheral space is an ability that emerges from 6 months of age.

Moreover, ERPs results indicate that 6-month-old infants, as well as adults, show a modulation of sensory components when a peripheral target appeared in a congruent position with walking direction (Experiment 8 and 9) demonstrating that walking direction can yield a gain control or selective amplification of the sensory information in the extra-cortical visual pathways.

Overall, these data demonstrate that detection of social agents relies upon motion cues and that our visual system is tuned, since birth, to specific cues of motion that define human kinematics. It is hypothesized that these cues of motion might be the building blocks on which our species infer and extract intentions of others (Biro & Leslie 2007; Carey, 2009) and that the experience with conspecific might shape our ability to use motion cues to orient attention toward the surrounding space. These conclusions are in line with the Neo/Neuro-Constructivist theory of cognitive development and suggest that experience with conspecifics play a fundamental role in shaping the human system that become specialized in detecting social agents.

Chapter 1

The origin of social brain in humans:

The Neo/Neuro-Constructivist approach

Introduction

A central question for developmental psychologists concerns the origin of knowledge in different domains. One of the peculiar characteristic of human beings is that they constantly interact with others and they are able to process stimuli in social context (Adolphs, 1999). A fundamental ability, that is at the bases of social cognition, is the capacity to accurately detect and understand the intentional conduct of others, to anticipate their upcoming actions, and to contingently adjust one's own behavior to other actions (Gallese et al., 2009). In adults, these social abilities seem to be supported by a neural network namely Social Brain. There is no doubt that before attributing goals, desires, dispositions to social agents, humans need to detect others in the environment, and they need to use and to extract perceptual cues that allow them to discriminate animate *versus* inanimate entities.

The following chapter will be devoted to present an overview of the major theoretical positions (i.e. Domain-general, domain-specific and Neo/Neuro-constructivist approaches) that describe the development of knowledge in humans. Subsequently, the Social Brain network in adults of human species will be presented and how the different theoretical viewpoints tried to describe the origin and the ontogenetic development of it. Specifically, it will be distinguished between theories that posit that mechanisms that humans inherited from their evolutionary history are general form those theories that state that these mechanisms are specific, and how visual experience shapes the progressive specialization to process social stimuli.

1.1 The two classical theoretical points of view of knowledge and cognitive development

Since the Ancient Greece, intellectuals and philosophers wonder about the developmental origins of the human knowledge. The different domains of knowledge can be defined as body of knowledge about a given topic that includes information about what entities are included in the domain as well as rules that describe how the entities in the domain behave (Rutherford, 2013). A classical debate that dominates developmental sciences, concerns the role of domain-general *versus* domain-specific mechanisms on human knowledge. Classical theories in developmental psychology might be divided on the two extremes of this debate.

Domain-general theories support the idea that knowledge emerges on the basis of domain-general mechanisms of learning (i.e. error driven) that are sufficient to explain how children and infants learn about specific domain of knowledge such as, for example, language, number, and space.

On the contrary, according to domain-specific theories, knowledge constitutes part of the human innate endowment. In this vein, the human mind is endowed with a set of special purpose mechanisms shaped, through adaption, to the environment during evolution, to perform specific functions. Nativism is at the bases of the domain-specific theories of development. Domain-specific theories maintain that human knowledge is built on domain-specific systems and that natural selection had favored the evolution of mechanisms that leads to this knowledge (Kellman, 1993). According to some authors, neonates and infants come into the world with domain-specific principles allowing them to process specific types of inputs (Spelke, 1990; Baillargeon & Wang, 2002), in different domains of knowledge such as number and faces (Spelke & Kinzler, 2007). In this vein, learning is guided by innately specified and domain-specific principles that determine the entities on which subsequent learning takes place (Gelman, 1990; Spelke, 1991).

The nativistic aspect of domain-specific viewpoint of development, was also influenced by Fodor's Modularity of Mind theory (1983). According to Fodor, humans are born with the innate capacity to develop information processing systems or "cognitive modules" that allow them to make sense of the world. Cognitive modules, as defined by Fodor (1983), are hardwired (not assembled from more primitive processes) of fixed neural architecture, domain specific, fast, autonomous, mandatory (higher level cognitive processes cannot curtail their operation), and stimulus driven.

A third perspective of development, that overcomes the classical debate between domain general and domain specific theories is Neo/Neuro-constructivist theory.

1.2 Neo/Neuro Constructivism

The Neo-Constructivist approach, as stated in the name, starts from Piagetian Constructivist theory. Piaget's position, well known as Epigenetic Constructivism, maintains that cognitive development is the product of a self-organizing system that is structured and shaped by its interaction with the environment. According to Piaget, the mind of newborns is knowledge free; but it is furnished of domain-general mechanisms (i.e. accommodation, assimilation and equilibration) that are the mechanisms that child use to build knowledge. These mechanisms, well known as functional invariants, through the interaction with the external world which is favorite along with innate reflexes (i.e. sucking, grasping) are the bases of knowledge. The most important thing in Piaget’s theory is that babies have an active role in the construction of knowledge. They act and interact with the external world, since birth along with innate reflexes and thank to the interaction between the external world and the functional invariants they build the cognitive structures of their mind.

Neo-Constructivism (literally, New Constructivism), combines the two different aspects postulated by nativism and epigenetic principles and assumes the existence of some innate specified predispositions that would trigger the epigenetic process in each domain of knowledge (Simion & Leo, 2010). In this sense, the dichotomy between domain-specific and domain-general mechanisms is overcome. Within this theoretical framework, the development is seen as a continuous process that emerges through the dynamic of a probabilistic epigenesis and that progressively leads to an increasing functional specialization of neural circuits (Bates & Elman, 1993; Johnson, 2011; Karmiloff-Smith, 1992). *“Probabilistic epigenesis (Gottlieb, 1992), considers that the development involves the progressive restriction of fate. Early in development, a system, such as the brain/mind, has a range of possible developmental paths and end states. The developmental path and end state that result, are dependent on the particular sets of constraints that operate during the development”* (Johnson, 2011 p. 12; Waddington, 1975; Gottlieb, 1992).

According to Neo-constructivist approach, cognitive activity is seen as emerging gradually as a product of the interaction between innate constraints and the structure of the input provided by the environment (de Schonen, 2002; Johnson, 1993; Nelson & Luciana, 2001). In this scenario, specific cognitive structures observed in adults may arise from primary, general innate constraints shaped by the nature of the experience the organism is exposed in a given period of time (Karmiloff-Smith, 1992). Constraints are not considered in a negative way, but they are defined as bases of information processing due to the properties of the brain or the perceptual system. This conceptualization of constraints differs from the innate domain specific modules as defined by Fodor (1983), but they are present since birth and help the cognitive system to organize the information that comes from the external world. These constraints, conceptualized as attentional biases, allow the system to have benefits such as focusing the cognitive system toward certain aspects of the environment or facilitating processing of certain types of inputs. The information recovered thank to these biases progressively tune the system to become specialized. Another important aspect conceptualized by Neo-constructivism is that, during development, there are crucial time windows such as critical and/or sensitive periods (Greenough, Black, & Wallace, 1987; Greenough & Black, 1992) during which the role of experience affects profoundly cognitive development. Critical period refers to the existence of time window strictly delimited during which a specific experience could have effect on the development. In contrast, sensitive periods are defined as those moments in which the organism is particularly sensitive to specific experiences, with no need to exclude that these experiences could continue to have influence also in successive time windows during the ontogenetic development (Macchi Cassia, Valenza & Simion, 2012).

To summarize, the Neo-constructivist approach overcomes the dichotomy of classical theories of development, and suggests that the specific outcome in cognitive development is the product of a process of modularization. The specificity of certain brain areas or cognitive processes is not pre-determined since birth, but rather emerges gradually during development. The natural selection and the evolution have pre-specified many innate general biases (constraints) and through them the babies experienced actively the world where they are embedded. These biases, general at the beginning, become selectively specialized as a function of the experience with the external world. In light of this, it is plausible to speak of a process of modularization since the modular architecture of the brain arises from a gradual development rather than to be modular from the origin.

The neuropsychological counterpart of Neo-Constructivism is the Neuro-Constructivism, which emphasizes the interrelation between brain development and cognitive development (Karmiloff-Smith, 1992; Quartz & Sejnowski, 1997; Sirois, Spratling, Thomas, Westermann, Mareschal, & Johnson, 2008). For the Neuro-constructivist approach, development is a progressive increase of the complexity of representations and development of new abilities based on earlier and simpler ones. The increasing of complexity of representations is the outcome of a progressive specialization of cortical structures. The step forward that Neuro-constructivism offers is that cognitive development is strictly related to the development of the underlying cortical structures in the brain. In this vein, constraints operate on development of neural structures that are at the bases of mental representations, and cognitive development is considered as a trajectory emerging from the interplay of these constrains. As mentioned before, also brain development is seen as derived from the progressive restriction of the fate of neurons and neural circuits. In other words, as development proceeds, neurons and cortical circuits become increasingly specialized, dedicated to particular functions and less capable of change. Also in this vein, the development of neural circuits is seen as a product of the interaction between internal constraints (anatomical and architectural constraints) and constraints that come from environment. Endogenous constraints select the aspect of the environment to which orienting attention and, interacting, with the neural structure of the input typical of the infants' environment, guide and shape the gradual emerging of specialized processing (Werker & Vouloumanos, 2001).

From a functional point of view, both Neo-Constructivism and Neuro-Constructivism, embraced the interactive specialization perspective suggesting that the development is the outcome of a constant interaction between environment and genes. These two aspects mutually interact each other and the development of brain structures is defined as experience expectant. Structures may initially have homogeneous response towards different types of inputs such as faces, and actions (Grossman & Johnson, 2007). With the experience, the neural circuits may become more differentiated and specialized in their responses, finally resulting highly specialized as in the adults' brain.

To conclude, Neo- and Neuro-constructivism, postulated development as a continuous process, starting from general predispositions that might be present since birth, and thank to the constant interaction with the experience that came from the environment the system will become specialized. In addition, it might be possible to design developmental trajectories for specified cognitive functions and for processing specific classes of stimuli.

According to this theoretical framework, and considering that humans are intensely social creatures, many researchers investigated the origins and the developmental time course trajectory of the "social brain".

1.3 The Social Brain

Humans are intensely social creatures. One of the most peculiar and unique characteristic of the human brain is the ability to process stimuli in a social context (Adolphs, 1999; Brothers, 1996). To perceive, detect, and discriminate humans from objects is critical for adaptive behavior considering that at the first stages of life, our survival is strictly dependent from caregivers and as a consequence to the infants' ability to detect them. Adults, are extremely proficient in all the cognitive processes that are at the bases of social cognition since our social interaction is strictly dependent on our abilities to understand the intentions of the conduct of others, to anticipate their upcoming actions, and to contingently adjust one's own behavior to other actions (Gallese et al., 2009). Certainly, a critical aspect of social cognition is social perception, that is the initial stage of evaluating intentions of others by the analysis of the behavioral cues such as body motion, hand gestures and facial expressions.

In adults, all these processes seem to be supported by a specific neural network, known as Social Brain (Adolphs, 2009). In accordance with the Social Brain Hypothesis, that states that social creatures are endowed with this specific network devoted to detecting, recognizing and perceiving social stimuli, several neuroimaging studies have tried to define which are the brain areas involved. Findings suggest that certain subcortical and cortical areas of the brain, such as the amygdala, the orbitofrontal cortex and the temporal poles are specialized for processing information that are peculiar of social agents, such as identity, behavior, and intentions (Brothers, 2002). More recent neuroimaging studies, extend the social brain network to other regions: the superior temporal sulcus (STS), the orbitofrontal cortex, and the fusiform face area (Allison, Puce, & McCarthy, 2000; Farah, Rabinowitz, Quinn, & Liu, 2000; Kanwisher, 2000;). It has been demonstrated that superior temporal sulcus is involved in processing a variety of social information. STS is activated when adults perceive human motion rather than other types of motion, such as random motion (Bonda, Petrides, Ostry & Evans, 1996; Grossman et al., 2000; Grossman & Blake, 2001), eye gaze shifts and mouth movements (i.e. Puce, Allison, Bentin, Gore & McCarthy, 1998), hands and other body parts actions (Rizzolatti et al., 1996; Pelphrey, Morris, Michelich, Allison & McCarthy, 2005). STS seems to be a key node of the social brain network in adults. Nevertheless, STS did not operate isolate but is strictly connected with others cortical and subcortical regions involved in Social Brain circuitry.

One of the most important debate in cognitive neuroscience is about the origins of the “social brain” in humans

1.4 The origin of Social Brain

From a phylogenetic viewpoint, it has been demonstrated that also many other vertebrates (i.e. chicks, and monkeys) orient their attention toward social agents. Specifically, newly hatched chicks detect others on the basis of the way they move (Regolin, Tommasi & Vallortigara, 2000). Similarly, monkeys manifest a preference for faces rather than objects (Sugita, 2008). This evidence seems to support the idea of the existence of hard wired mechanism to detect social stimuli. This mechanism might be present, since birth, in animals as well in humans (Johnson, 2007).

From an ontogenetic point of view, researchers tried to explain the origin of the social brain according three different perspectives of functional development of cognition (i.e. maturational, skill learning, interactive specialization; Johnson 2001; 2005).

According to the maturational perspective, the evolution has been selected specific parts of the brains that become dedicated to process social information. Some of these areas are present and active since birth, whereas other parts will become functioning later during development according to specified maturational timetable. The experience has no role in affecting the timetable of maturational process. On the contrary, the skill learning hypothesis postulates that social stimuli are not different from other type of inputs. Brain areas deputed to process social information are not specialized because of the social nature of the stimuli (i.e. domain specificity), but because the constant experience with social stimuli shaped the brain areas (process specificity). It is hypothesized that the regions active in infants during the onset of new perceptual or behavioral abilities are the same as those involved in skill acquisition in adults (Johnson, Grossman, & Farroni, 2008).

According to Neo- and Neuro-Constructivism and the interactive specialization perspective, the social brain would develop as an outcome of the interaction between initial biases and the experience with the environment. From this viewpoint, the neural circuits of the social brain are the product of the organization of cerebral cortex areas that are initially broadly tuned and become progressively more specialized (Johnson, 2001). Starting from the constructivist theory, the interaction with the environment generates structural changes in brain areas that co-develop with functional changes in cognitive processes (Johnson, 2000), and the timing of events plays a critical role in developmental trajectories.

In other words, the specialization of the cognitive system cannot be ascribed to pre-specified regions, but to a particular sequence of interactions between cortical circuits and the pre- and post-natal environment, resulting in successive reorganizations of the cortical circuits themselves. (de Schonen, 2002).

In this vein, social brain arises from a constant interaction between cortical circuits and experience. For example, at birth brain cortex is not fully developed but subcortical structures are functioning. Studies with newborns demonstrated that superior colliculus is completely functioning (Simion, Valenza, Umiltà, Dalla Barba, 1995) and might support orienting of attention since birth so that to explain newborns' capability to process potentially relevant information in the surrounding space. It has been hypothesized that subcortical structures continuously send inputs to cortical region and together with the experience and the interaction with co-specifics, may contribute to the specialization of cortical brain areas involved in the social brain network.

In line with the interactive specialization hypothesis, the present thesis will examine the emergence of the specialized cognitive system devoted to processing kinematics of social agents and the role of perceptual biases and experience in contributing to the development of the social brain.

1.5 Detecting agents based on motion cues

As aforementioned, at the basis of social cognition, there is the capacity to accurately detect and understand the intentional conduct of others (Gallese et al., 2009). Moreover, there is also no doubt that before attributing goals, desires, dispositions to social agents, humans need to discriminate animate *versus* inanimate entities. It has been demonstrated that social stimuli such as faces, play a central role in detection and recognition of others. Another cue that allow animal species to differentiate animate from inanimate objects is "the way they move". Indeed, a feature that is constantly present during social interaction is motion. With the term motion, we usually can refer to body motion, face expressions and hand gestures. Certainly, kinematics of humans, as well as of other vertebrates, is peculiar and characterized by specific cues of motion, such as self-propulsion and patterns of acceleration and deceleration. For example, when vertebrate walks, the pattern of motion of each single step has an accelerated-decelerated sequence. The acceleration phase preceded the deceleration at the beginning of each step (e.g. when the foot starts moving) and deceleration is at the end of the action, when the body parts are approaching a surface.

In light of this, as well with other social stimuli, it might be plausible to hypothesize that social perception might be built on perceptual cues that characterize living entities.

In this vein, the present thesis will examine and try to design a developmental trajectory for the detection of social agents based on kinematic cues that characterize animate entities and the biological motion of the legged vertebrates.

According to Moore (2012) as described in Chapter 3, a terminological clarification is necessary among the three terms of “animate motion”, “biomechanical motion” and “human motion”. Traditionally these terms have been used to refer to different topics. However, considering the kinematics proprieties of motion of living being the three terms can be considered as different levels of a unique taxonomy based on motion features (see figure 1.1). Animate motion is located at the most general level of this taxonomy and refers to motion of animate entities characterized by visual motion cues, such as self-propulsion and acceleration-deceleration sequence that trigger animacy perception in adults. Biomechanical motion, as defined by Moore (2012), is used to refer to motion of legged vertebrates (i.e. bipeds and quadrupeds). Motion of legged vertebrates is characterized by the same motion cues that define animate motion but in addition these cues of motion are also bound to the constraints of the vertebrates' skeleton. Finally, human motion refers only to motion of human beings where kinematic cues that define animate motion are constrained by the human body that possesses arms and legs vertically aligned.

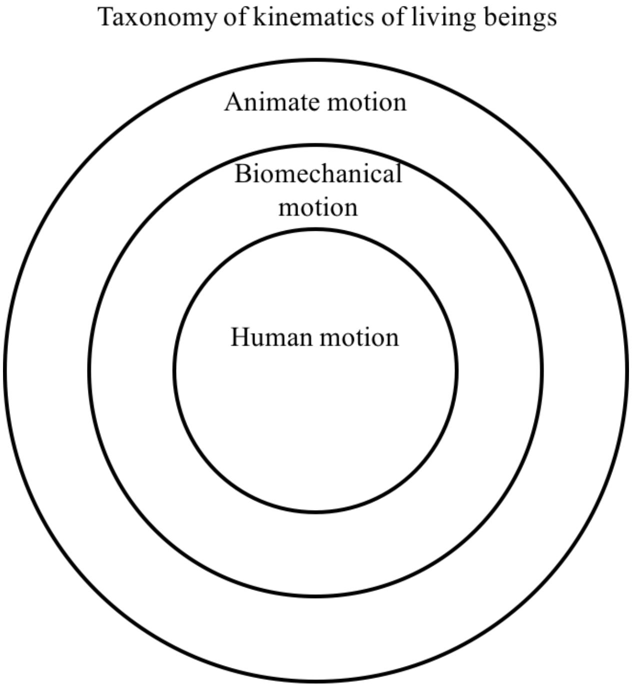

Figure 1.1 Schematic representation of the Taxonomy of the kinematics of living beings

Previous findings demonstrated that adults, simply by analyzing kinematics information, can retrieve multiple types of social information such as gender, emotion and identity that are relevant for detecting and interacting with others. (i.e. Dittrich, Troscianko, Lea, & Morgan, 1996; Troje & Westhoff, 2006; Hirai, Saunders & Troje, 2011). Indeed, studies conducted with adults demonstrated that brain areas involved in the Social Brain network are sensitive to motion that characterized humans. As aforementioned, it has been demonstrated that brain regions of adults' brain, such as STS, selectively respond human motion (Pavlova, 2012). Stimuli employed with adults were complex arrays of dots (point-light display, PLD, Johansson 1973; 1976) in which the only retrievable information is kinematic.

From a developmental perspective, several studies which employed PLDs with human newborns and infants, demonstrated that babies are able to discriminate and prefer human motion rather than other type of motion, such as random motion (Fox & McDaniel, 1982; Bidet-Ildei, Kitromilides, Orliaguet, Pavlova, & Gentaz, 2014). This evidence guides authors to hypothesize that our visual system might be equipped of a visual filter specifically tuned for perceiving motion of vertebrates' legs (Troje e Westhoff, 2006; Johnson 2006; for a complete description of the model see Chapter 3).

There is no doubt that motion is one of the most powerful visual cues that triggers newborns' attention. As suggested by Troje and Westhoff (2006) and Johnson (2006), the visual filter tuned for the perception of motion of legged vertebrates might be present since birth. However, according to Neo/Neuro-Constructivist approach, it might be plausible to hypothesize that at birth our visual system possesses some general biases toward perceptual motion cues that characterize animate motion such as, for example, self-propulsion and acceleration-deceleration patterns. These biases might be the building blocks on which, during the development, humans built their ability to process quickly and accurately human motion.

The aim of this thesis is to examine the emergence of the specialized cognitive system devoted to process kinematics of social agents and how inborn perceptual biases contribute to the development of the social brain.

To this end, Chapter 2 will be devoted to the description of a series of experiments that investigate newborns' sensitivity to some visual cues that in adults elicit animacy perception: self-propelled motion, directional and speed changes cues of motion. Moreover, percepts of animacy may also be driven by more specific types of motions cues, such as when the motion of a complex arrays of dots is organized and perceived as a particular form of human motion (i.e. human walker, Scholl & Gao 2013). The infants' ability to extract information of directionality from PLD of a human walker might be facilitated by the fact that motion information is conveyed by a PLD that represents the constraints of the human body. In light of this, as suggested by Frankenhuis and Barrett (2013), the detection and recognition of motion pattern when they are depicted as a human body might be facilitated by the action schemas that might be present in the infants' motor repertoire.

For this reason, in Chapter 3, 3- and 6-month-old infants, and adults were presented with a PLDs of a human walker to test their ability to extract directionality from complex arrays of dots, and to test how the information of directionality can trigger infants and adults' attention toward the surrounding space.

Chapter 2

Newborns’ sensitivity towards visual cues of motion that trigger Animacy Perception[*]

2.1 Animacy perception in adults

The world in which we are embedded is extremely complex. However, despite this complexity, adults, infants and even newborns can organize and structure it. The first and the most important way of making sense of the world is to identify and to differentiate social entities from non-social ones. The ability to discriminate between social and non-social entities might be considered the first step towards interaction with others. Moreover, from an evolutionary point of view, this distinction is also at the bases of survival for our species.

Due to its adaptive relevance, some authors hypothesized that, in the adult brain, the dichotomy and the discrimination between animate and inanimate objects is a domain-specific knowledge system that is supported by a specific neural mechanism (Caramazza & Shelton, 1998; Mahon & Caramazza, 2009; Schultz, Friston, O’ Doherty, Wolpert & Frith, 2005; Vallortigara, 2012). Additionally, according to the animate monitoring hypothesis (New Cosmides & Tooby, 2007), human adults possess an ancestrally derived domain-specific subsystem within visual attention, that is automatic, independent from beliefs, goals and acquired experience, for detecting the presence of

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[*] Part of the content presented in this chapter has been described in the following published article: Di Giorgio, E., Lunghi, M., Simion, F., & Vallortigara, G. (2017). Visual Cues of Motion that trigger Animacy Perception at Birth: The Case of Self-propulsion. *Developmental Science, 20(4)*.

animate beings and monitoring them (New et al., 2007; Pratt, Radulescu, Guo & Abrams, 2010).

Whether the distinction between animate vs. inanimate objects is present from birth, on which visual cues is based, as well as how it develops thanks to the visual experience are intriguing open questions.

Adults detect social agents not only on the basis of static visual cues such as facial features (Kanwisher, 2000), the presence of the eyes (Puce, Allison, Gore & McCarthy, 1995), and body structure (Downing, Jiang, Shuman & Kanwisher, 2001), but also on how they move, i.e., biological motion (Troje, 2013; Vallortigara, Regolin & Marconato, 2005; Vallortigara & Regolin, 2006). Even more interesting, also geometrical moving shapes can be perceived as animate by adults, a phenomenon known as *perceptual animacy* (Rutherford, 2013; Santos, David, Bente & Vogeley, 2008; Scholl & Gao, 2013; Scholl & Tremoulet, 2000). In line with the main aim of this thesis, here I am concerned with this perceptual level, which can be considered consistent with the more basic level of animacy conceptualized by Scholl and Gao (2013), which suggests that phenomena of perceiving animacy reflects visual processing that is specialized for the extraction of animacy from visual motion.

As first demonstrated by Hider and Simmel (1944), animations of simple geometrical shapes (i.e. a circle, a square and a triangle) that moves and interacts each other can elicit a perception of animacy solely based on kinematics information. Specifically, adults attributed internal states, intentions, emotions, and roles to the geometrical shapes, but the only thing that they saw were three different figures that moves on the monitor.

Starting from this pioneering study, and considering the importance of animacy in the study of social cognition, a wide number of researchers tried to identify the relevant trigger factors or constituents for human perception of animate motion. Self-propelled motion, such as when an object begins to move without a perceivable external cause, has been identified as the most relevant or at least the most consistent determinant in animacy perception (Leslie, 1994; Stewart, 1984). Changes in direction (Dittrich & Lea, 1994; Scholl & Tremoulet, 2000; Szego & Rutherford, 2008; Tremoulet & Feldman, 2000), speed changes (Tremoulet & Feldman, 2000), discontinuity in motion trajectory, motion contingency, and violation of Newtonian laws (Gelman, Durgin & Kaufman, 1995; Santos et al., 2008; Bassili, 1976; Blakemore, Boyer, Pachot-Clouard, Meltzoff, Segebarth et al., 2003; Kaduk, Elsner & Reid, 2013) are other cues of motion that trigger animacy perception in adults. Motion contingency (spatial and temporal synchrony) has also been referred to as a fundamental requisite to perceive motion as animated (Bassili, 1976; Blakemore et al., 2003; Johnson, 2003; Johnson, Booth, & O’Hearn, 2001). Furthermore, the degree of interaction between objects (potential agents) also increases the impression of animacy (Dittrich & Lea, 1994), which relates to perceiving the motion as goal-directed.

However, researchers studying animacy perception employed relatively complex displays that involved the interaction between multiple moving shapes and environmental elements (obstacles, boundaries). More recently, researches tried to disentangle which specific motion cue mediates perceptual animacy using simple schematic displays. The use of simple display has clear advantages: it allows to researcher to manipulate exact motion parameters and to examine the effect of the cues of motion on the perception of animacy (Rutherford, 2013). A first study that employed single visual object moving on a homogeneous background was done by Tremoulet and Feldman (2000). In this study, adult participants were presented with a single object that moves along a trajectory and suddenly accelerate and change its own trajectory. Results showed that adults perceived as more animate an object that change speed with an increasing of acceleration and also change direction more acutely. Subsequent research replicated and extended these findings: human adults consistently attribute higher animacy to single shapes moving against gravity and changing autonomously speed or direction of motion; for stimuli moving at a constant speed, the higher was the speed, higher was the animacy attribution (Gyulai, 2004; Szego & Rutherford, 2007, 2008).

However, the origin of perception of animacy is still unclear. As mentioned before, some authors argued that animacy perception is supported by domain-specific mechanism (Premark, 1990, Biro & Leslie, 2007) and this mechanism is might be innate (Mandler, 2003). On the other hand, some authors state that animacy perception it might be supported by domain-general mechanism, such as associative learning, that through experience with specific kinds of entities babies become specialized to detect specific features of motion (Rakinson, Lupyan, Oakes & Walker-Andrews, 2008).

Developmental studies might shed light and give some answers about the presence at birth of the sensitivity to visual motion cues that trigger animacy in adults.

2.2 The origin of animacy perception

Since in adults, animacy phenomenon is based on fast and automatic visual processing, it is plausible to hypothesize that animacy perception has an early ontogenetic origin which is mainly constrained by a collection of low-level visual cues of motion. Developmental research has demonstrated that preverbal human infants are able to distinct between animate and inanimate entities, and they also demonstrated that motion cues provide a decisive role in the classification of objects into these categories (Baker, Pettigrew & Poulin-Dubois, 2014; Gelman, 1990; Mandler, 1992; Poulin-Dubois, Crivello & Wright, 2015; Premack, 1990; Saxe, Tzelnic & Carey, 2007; Spelke, Phillips & Woodward, 1995; Surian & Caldi, 2010; Träuble, Pauen & Poulin-Dubois, 2014). Behavioral evidence has demonstrated that 12-month-old infants are sensitive to motion that characterize animate entities. Specifically, infants were tested with two different experimental conditions. In the first condition defined as stationary condition, infants were familiarized with a robot that remained stationary; in the second condition, namely self-propulsion condition, the robot starts to move autonomously and changes direction during its trajectory. Results showed that 12-month-old infants were surprised when the robot moves autonomously, suggesting that around the first year of life infants are sensitive to motion cues that characterize animate entities. Moreover, in the second experiment of the same study, 9-month-old infants underwent to the same experimental condition and also in this case, 9-month-old infants were surprised when the robot moves following the motion pattern that is characteristic of animate entities (Poulin-Dubois, Lepage & Ferland, 1996). Additionally, Kaduk and colleagues (2013), tested 9-month-old infants in a ERP study. Infants were presented with a simple geometrical shape that in one condition was moving in a self-propelled manner and was violating Newtonian laws of motion to induce a judgement that the object was animate, and in the other condition the object changes motion only due to external forces (i.e. inanimate condition). ERPs results, showed that infants allocate more attentional resources (i.e. more negative peak of NC component) to inanimate condition, suggesting that they were able to discriminate between animate and inanimate motion based on motion cues. Moreover, another study tested younger infants, showed that cues of motion, such as self-propulsion can lead infants to attribute goals to the action of non-human agents. In the study conducted by Lou and Baillargeon (2005), 3- and 5-month-old infants were tested with a familiarization paradigm in which an object (i.e. a box) suddenly starts to move and approach another object. Moreover, two experimental condition were present; in the first condition, namely, short handle condition, the box have short handle that is totally visible inside the apparatus; in contrast, in the second condition, namely long handle condition, the handle was longer and it went out of the apparatus make the motion of the box ambiguous. The ambiguity of the self-propelled motion, was due to the fact that infants did not know if the object was moving by a hand or not. Such ambiguity was not present in the short-handle condition, because the object start to move autonomously. Results showed that 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 action as goal directed. These findings suggest that infants can attribute goals to a non-human object when it is moving with motion pattern that is specific of animate entities (i.e. self-propulsion), suggesting that infants, also from 3 months of age, use motion cues, such as self-propulsion, to distinguishing between animate and inanimate entities. (Lou & Baillargeon, 2005). This study demonstrated that infants use motion cues to categorize object. However, all these studies did not directly test infants’ sensitivity to motion cues that trigger animacy perception.

Since studies on animacy perception have never involved infants younger than 3 months of age, these studies can not exclude the possibility that experience during the first 3 months of life may shape the responses of infants towards animate objects. For this reason, the studies present in literature did not answer to the question about the origin of animate vs. inanimate distinction and, therefore, studies on human newborn are needed.

From a domain-specific viewpoint, it has been suggested that this precocious sensitivity to self-produced motion as a critical cue to differentiate animate from inanimate objects is due to the existence of an innate, domain-specific visual module present from birth (Premack, 1990). The primacy of motion as a cue for identifying animate entities has also been acknowledged by Mandler (2003), who proposed that infants develop knowledge about motion cues of animate entities through the innate process of perceptual analysis. In the same vein, other authors have hypothesized that at birth, infants possess separate core knowledge systems for animate and inanimate objects, and that they understand that constraints on motion that apply to physical objects may not hold true for animate beings (Spelke, 2004; Spelke & Kinzler, 2007). In contrast, according to a more domain-general view, as in associative learning, infants use learning mechanisms that operate across all domains of knowledge to encode statistical regularities in their environments. Therefore, infants learn about identities and properties of the objects that appear in self-propelled events through their experiences with specific kinds of entities that engage in these motions (Rakison et al., 2008; Rakison & Poulin-Dubois, 2001).

The first evidence that can answer to the question whether animacy perception is present since birth, and without any kind of experience, came from studies that employed chicks as animal model. In the studies conducted by Mascalzoni and colleagues (2010) and by Rosa-Salva and colleagues (2016), chicks were tested without any kind of experience. It has been demonstrated that newly hatched chicks are sensitive to self-propelled motion and speed changes. Mascalzoni and colleagues (2010), first demonstrated that chicks with no previous visual experience, shown a spontaneous preference for self-propelled visual cues of motion. Specifically, on their first day of life, chicks were exposed to an animation sequence depicting two oval-shaped objects, and each object was a different color. In the animation sequence, a given object was set in motion either by self-propulsion (i.e. it started moving on its own) or by the application of an external force (i.e. by direct contact with a second object) or in a third case, motion onset was ambiguous, that is, at the time of motion onset the object was hidden behind occluding screens and therefore, no cues were provided about the nature of motion onset. After exposure to the animation sequences, the spontaneous preference of chicks for these scenarios was tested and chicks preferred the self-propelled object. These results demonstrated that the domestic chick, a highly precocial bird species, showed an innate sensitivity to self-propulsion and this may be because self-propulsion is a crucial cue to animacy. In the same way, Rosa-Salva and collaborators (2016) tested newly hatched chicks' spontaneous preference for approaching an object that moves with a constant speed and trajectory, along a horizontal trajectory, compared to an identical object that suddenly linearly accelerated and then decelerated again to the original speed. Chicks showed a significant preference for the speed change stimulus. The visual preferences found in newborn visually naïve chicks for self-produced motion and speed changes seems to be at the basis of the predisposition for identifying animate creatures demonstrated that, at birth, visual system have some attentional biases to detect visual cues of motion that trigger animacy perception in adults.

What about human species? Does the ability to discriminate between animate and inanimate objects based on motion cues, described in chicks, also hold true in human newborns?

To answer these questions the six experiments presented in this chapter investigate the visual cues of motion that are the precursors of animacy perception in adults. In the six experiments visual cues of motion, such as self-propelled motion, change in direction, and speed changes, were systematically tested. Using a visual preference paradigm, in the Experiment 1 self-propelled object were compare to ambiguous one (i.e. the moment when the object starts to move was hidden by an occluder). In the Experiment 2, change direction cues of motion were tested. Using the same paradigm of the Experiment 1, an inert object, which change direction only after a collision with an occluder, was compared to another identical object that, instead, change direction autonomously, without any external contact.

In experiments 3, 4, 5, and 6 were tested speed changes visual cues of motion. In experiment 3 and 4, a single speed changes (acceleration, Experiment 3; deceleration, Experiment 4) were tested using a visual preference paradigm compared to an object that moves with a constant speed. In Experiments 5 and 6 the acceleration and deceleration was combined to test whether speed changes cues have an additive value in animacy perception in newborns. Findings with chicks and human adults (Gyulai, 2004; Rosa-Salva, Grassi, Lorenzi, Regolin & Vallortigara, 2016) demonstrate that also speed change is an important cue that trigger animacy perception. Moreover, results with adults and chicks, revealed that the acceleration and deceleration elicit perception of animacy when they are present together rather than singularly. In addition, results from Gyulai's study (2004) suggest that in adults also the order of presentation counts.

Indeed, adults rate as more animate an object that suddenly accelerates and then decelerates rather than an object that decelerates and then accelerates. Also in these two last experiments, the speed changes event was compared to an object that moves with a constant speed.

Experiment 1: Self-Propulsion – Visual preference paradigm

The aim of Experiment 1 was to test the presence of an inborn sensitivity to a visual cue of motion that in adults triggers animacy perception such as self-propelled motion onset of an object when the object starts from rest on its own without any external force. Newborns were presented with two computer-generated events in which the visibility of the self-propelled motion onset of an object was manipulated (i.e. self-propelled vs. ambiguous). In the self-propelled motion event, the object started from rest with a self-initiated visible movement; therefore, its initial starting motion was clearly visible and available to the babies. In contrast, in the ambiguous event the object appeared on the screen already in movement, so no cues about the onset of motion were available to newborns. As demonstrated in Mascalzoni and colleagues' study (2010) with chicks in the present experiment newborns were tested with a single object that start to move autonomously (self-propelled event) compare to an object which start of motion was masked (ambiguous event). If newborns are sensitive to self-propelled motion cues, then they should prefer the event in which the onset motion of the object by self-propulsion is visible and not ambiguous.

Method

Participants

Eighteen full-term newborns were selected from the maternity ward of the Paediatric Clinic of the University of Padova. Data from six newborns were discarded because they became too tired or started crying during testing (n = 3) or showed a position bias (newborns looked in one direction more than 80% of the time, n = 3). Therefore, the final sample consisted of 12 newborns (seven males). Their postnatal age ranged from 13 to 98 h (M(age) = 40 h, SD = 27). All subjects met the normal delivery screening criteria, had a birth weight between 2380 and 4140 g (M = 3245 g, SD = 476), and had an Apgar score of 10 at 5 min. Newborns were tested only if awake and in an alert state, and after the parents had provided informed consent. All experimental procedures have been licensed by the Paediatric Clinic of the University of Padova.

Apparatus and Procedures

An infant-control preferential looking technique was used. Stimuli consisted of two animation events presented on an Apple LED Cinema Display (Flat Panel 30″) computer monitor (refresh rate = 60 Hz, 2560 x 1600). The baby sat on an experimenter’ s lap at a distance of approximately 30 cm from the monitor and white curtains were drawn on both sides of the newborn to prevent interference from irrelevant distractors. Eye movements were recorded with a video camera placed above the monitor, and the direction and duration of the first fixations, the total number of orienting responses and the total fixation time towards the stimuli were coded off-line. In accordance with Cohen (1972), I assumed that the number of orienting responses indexed an orienting mechanism, whereas duration of the first fixations, as well as the total fixation time, indexed a detection mechanism. At the beginning of each preference test trial, a red disc on a black background appeared to attract the infant’ s gaze to the center of the monitor. In a continuous fashion, the disc changed in size from small (1.8

cm) to large (2.5 cm) until the newborn’ s gaze was properly aligned with the red disc. The sequence of trials was then started by a second experimenter who watched the newborn’ s eyes through the video camera. When the newborn’ s gaze was aligned with the red disk, the second experimenter pressed a keyboard key that automatically turned off the central disc and activated the onset of the stimuli, thereby initiating the sequence of trials. Because stimuli were presented bilaterally on the left and the right side of the monitor with a convergent motion pattern (from peripheral to the central visual field), each newborn was given two paired presentations (trials 1 and 2) of the test stimuli. In each trial, the position of the stimuli was reversed (the initial left– right order of presentation was counterbalanced across subjects) (Figure 2.1). A trial ended when the newborn did not fixate on the display for at least 10 s. Videotapes of the newborn’ s eye movements were coded off-line by a different observer, unaware of the stimuli presented. The mean estimated reliability between observers was Pearson’ s r = .98, p < .001.

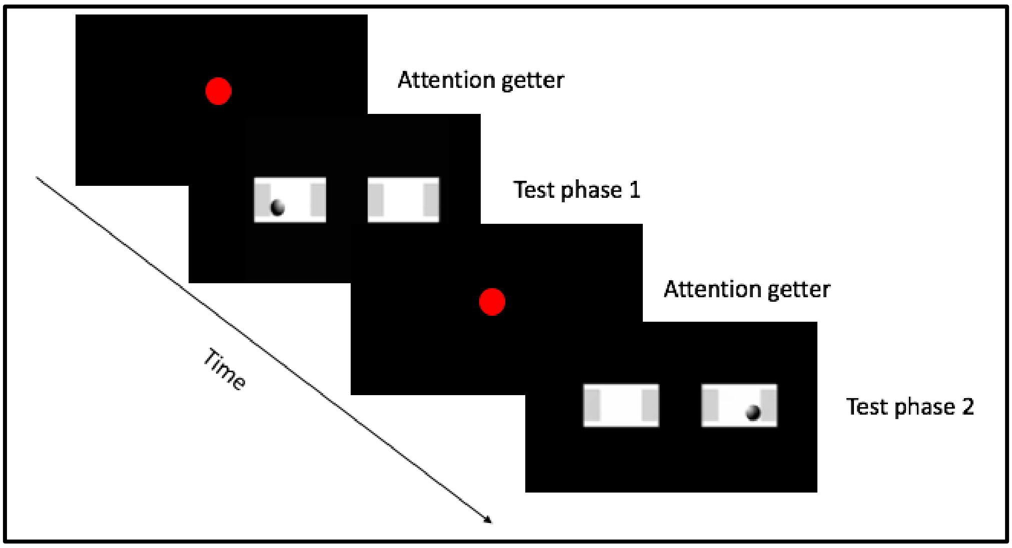

Figure 2.1 Schematic representation of visual preference paradigm

Stimuli

Stimuli consisted of two animation events presented on a computer screen: a self-propelled motion event and a non-self-propelled motion event. Each event featured two occluders (grey rectangles with an area of 4 x 8.5 cm, 7.6° x 15.8°), placed on the left and right, respectively, and one object (grey disc of 3 cm in diameter). In the self-propelled motion event, the object was already present on the screen near the first occlude and after 0.5 s it started to move on its own towards the second occluder, until it completely disappeared behind it. In this event, there were cues about the self-propelled nature of the object in motion. In contrast, in the nonself- propelled motion event, the entrance of the object was ambiguous (i.e. masked), because it appeared already in motion emerging from behind the first occluder; therefore, no cues about whether motion onset was driven by self-propulsion or external force were available. After emerging from the first occluder, the object continued moving towards the second occluder (as occurred in the self-propelled event) but then it stopped in front of the second occluder for 0.5 s. I chose to include this 0.5-s stop to ensure that in both animation events, the two stimuli remained the same amount of time in a static position (i.e. 0.5 s at the beginning of the self-propelled motion event and 0.5 s at the end in the ambiguous display. Importantly, both objects moved with identical speed and covered the same distance; Figure 2.2). In this type of display, adult subjects perceive the object already present on the screen that started to move as a self-propelled object, compared to the object in the ambiguous display. Both events described lasted 4.5 s (84 frames, 25 frames/s). Each object covered a distance of 11 cm at 4 cm/s and maintained both its starting and final position for 0.5 s. Videos were produced by looping the animations.

Each set of elements occupied an overall 10 cm window in width (20° visual angle at a viewing distance of 30 cm) (Figure 2.2).

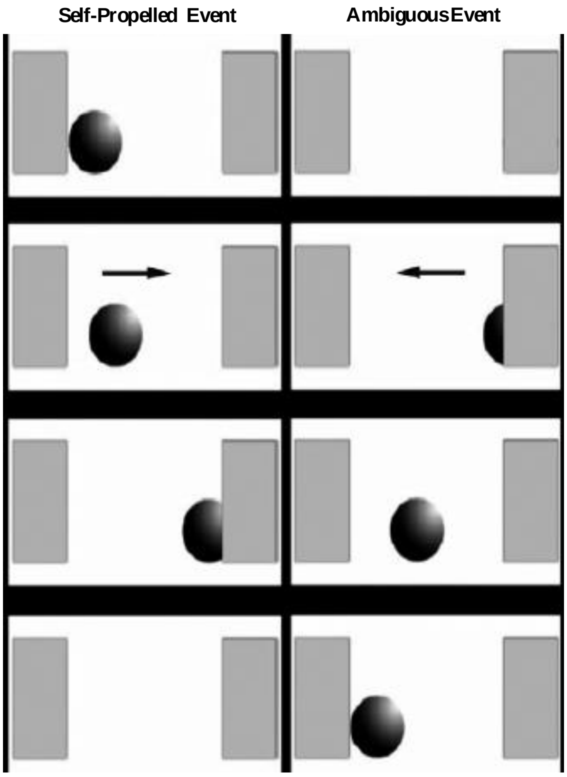

Figure 2.2 Schematic representation of stimuli employed in Experiment 1. On the left column, the self-propelled event; on the right column, the ambiguous event.

Results

The Kolmogorov-Smirnov goodness-of-fit test showed that the data were normally distributed. To establish whether the newborns showed a spontaneous visual preference for one of the two stimuli, separate two-tailed dependent samples t -tests were performed. When tested for their preference for a self-propelled motion event vs. an ambiguous motion event, newborns looked significantly longer at the self-propelled event (M = 41.6 s, SD = 18) than at the ambiguous one (M = 33.8 s, SD = 20.2), t(11)

= 2.3, p = .039 (Cohen’ s d = .68). Ten out of 12 newborns preferred the self-propelled motion event compared to the other event (binomial test, p = .039). The percentage of total fixation time newborns spent looking at the self-propelled motion event was significantly above chance level of 50% (M = 58.2%, SD = 10), t(11) = 2.9, p = .014 (d = .84). As regards the number of orientations, newborns did not look significantly more frequently to self-propelled motion event (M = 12.1, SD = 4.3) compared to the ambiguous one (M = 10, SD = 4.7), t(11) = 1.4, p = .17, ns (Figure 2.3).

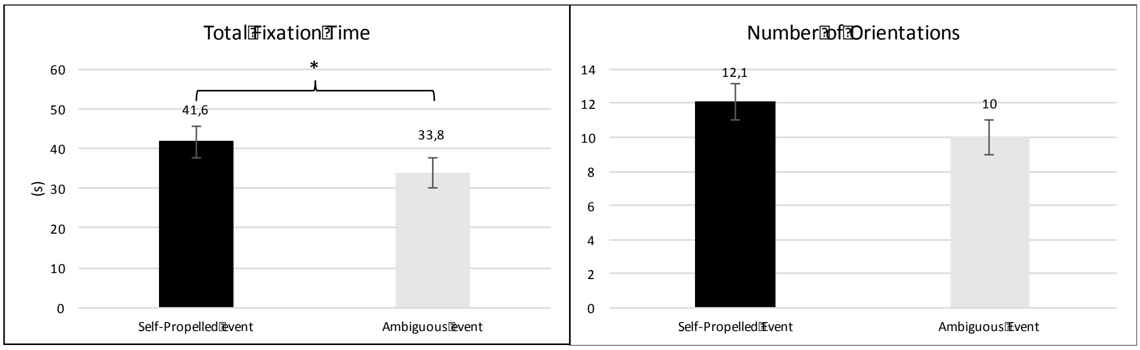

Figure 2.3 Average total fixation time (s) and number of orientations for the self-propelled motion and the ambiguous events in Experiment 1. Significant differences (*p* < .05) are marked with “*”

With respect to the duration of the first orientation, babies looked longer at the self-propelled motion event first (M = 7.3 s, SD = 4) compared to the ambiguous event (M = 5 s, SD = 3.2), t(11) = 2.6, p = .025 (d = .75). In addition, in test phase 1, 7 out of 12 newborns oriented first at the self-propelled motion event (binomial test, p = .77, ns), and in test phase 2, 6 out of 12 newborns oriented first to the self-propelled motion event (binomial test, p = .26, ns). Of note, in the self-propelled motion event, the first look measure does not begin at the exact time when the object starts to move. This is because at the beginning of each loop event, there is a 0.5-s time in which the object remains present on the screen. For this reason, I decided to conduct further analyses in order to investigate whether the sudden onset motion per se attracted newborns' attention. I analyzed the location where newborns were looking at the exact time when the object started to move. To do so, I calculated the total number of orientations towards the object that started to move on its own and divided this number by the total number of orientations towards both stimuli at the same exact time, x100. If the sudden onset motion per se triggers newborns' attention, then I should find that newborns look more frequently at the sudden onset motion in the self-propelled motion event. But this was not the case. The percentage of the number of orientations toward the onset motion of the object vs. motion in ambiguous display at the time when the object started to move was not above the chance level of 50% (M = 54.2% SD = 11.7, one sample t -test t (11) = 1.2, p = .24, ns. Finally, I carried out a further analysis by examining the looking behavior of newborns when the object started to disappear in the self-propelled motion event, in order to investigate an alternative explanation for the significant results obtained here, that is a possible preference for a disappearance event. Specifically, I analyzed the location where newborns were looking at the exact time when the object started to disappear behind the occluder in the self-propelled display (end of the event). I decided to concentrate the analyses on the exact time when the object started to disappear behind the occluder because all newborns, once their attention is captured by that exact time, continued to look at the disappearance event throughout its duration. If the disappearance event per se triggers newborns' attention, then I should find that newborns look more frequently (i.e. made more orientations) at the object that disappeared. However, the percentage of the number of orientations toward the disappearing object, calculated as the total number of orientations towards the disappearing object divided by the total number of orientations towards both stimuli at the same exact time, x 100, is not above the chance level of 50% (M = 51%, SD = 12, one sample t -test (11) = .23, p = .82, ns). I can conclude that the results in Experiment 1 are not due to a preference for a disappearance event (self-propelled) over an object appearance event.

Overall, Experiment 1 showed that newborns prefer the self-propelled motion event, where an object starts to move on its own without an external force, in contrast to an event in which the entrance of the object is ambiguous, where no visual cues about the onset of its motion are available.

Experiment 2: Change in Direction - Visual Preference Paradigm

As well as the onset of motion by self-propulsion, changes in trajectory direction by self-propulsion are important visual cues in triggering animacy perception in both adults (Tremoulet & Feldman, 2000) and infants (Luo, 2011; Luo & Baillargeon, 2005). In Experiment 2, the entrance of the object was masked as in the ambiguous event of Experiment 1; for this reason, it appeared on the screen already in movement. In the case of the self-propelled motion event, the object changed its trajectory, to move in the opposite direction, and stopped at the center of the screen (without encountering either occluder). In contrast, in the inert event, the object changed its trajectory towards the opposite direction after contacting an occluder, and then stopped at the center of the screen. In this experiment, the perceptual cue that revealed self-propelled motion was the change of direction with and without an external force (the occluder).

Method

Participants

The final sample comprised 12 healthy, full-term newborns (five males). Their postnatal age ranged from 14 to 175 h (M(age) = 44 h, SD = 42). All of them met the screening criteria of normal delivery, had a birth weight between 2185 and 3970 g (M = 3087.9 g, SD = 508), and had an Apgar score of 10 at 5 min. Two babies were excluded from the final analyses because they changed their state during testing.

Apparatus and Procedure

The apparatus and the procedure were identical to that used in Experiment 1. The mean estimated reliability between coders was Pearson' s r = .87, p < .01.

Stimuli

Stimuli consisted of two animation events presented on a computer screen (a self-propelled motion event and non-self-propelled motion event) and, as in Experiment 1, each event featured two occluders on the left and right (grey rectangles with an area of 3 x 8.5 cm) and one object (grey disc of 3 cm in diameter). Unlike the previous experiment, in this case the entrance of the object was masked (or ambiguous) in both events, because it appeared from behind the occluder already in motion, so no cues about the onset (by self-propulsion or by external force) of its motion were available. Therefore, the two events were equivalent with regard to the nature of the onset motion of the object. However, in the self-propelled motion event, the object changed its trajectory direction and went back and stopped at the center of the animation event without any contact with the occluder (the distance between the object and the occluder was 1 cm). In contrast, in the inert event, the object changed its trajectory direction by contacting the occluder and then went back and stopped at the center. In both events, the object remained at the center of the animation event for 0.5 s; thereafter the animated sequence restarted (Figure 2.4). Therefore, contrary to Experiment 1, here the visual cue that revealed self-propelled motion was a change of direction with and without an external force (the occluder).

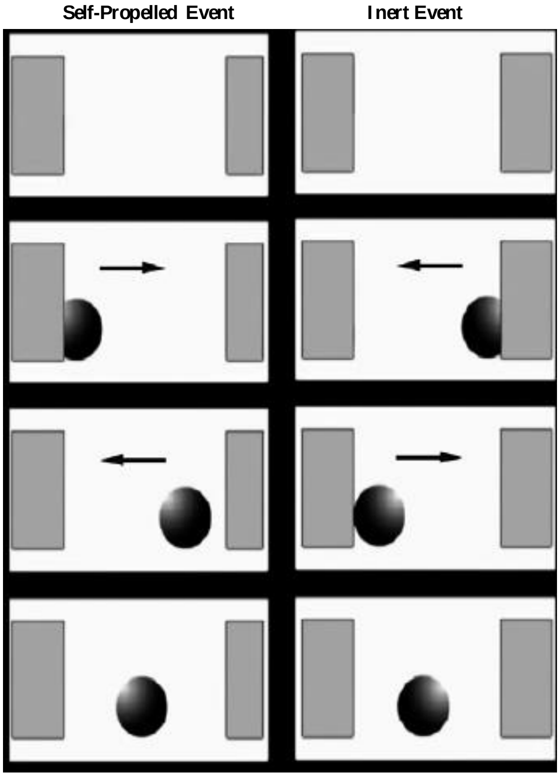

Figure 2.4 Schematic representation of stimuli employed in Experiment 2. On the left column, the self-propelled event; on the right column, the inert event.

Results

Since data were normally distributed as indicated by the Kolmogorov-Smirnov goodness-of-fit test, separate two-tailed dependent samples t -tests were performed. Newborns did not look significantly longer at the self-propelled motion event (M = 47.5 s, SD = 15.3) compared to the inert event (M = 45 s, SD = 24), t(11) = .39, p = .70, ns) (Figure 2). Eight out of 12 newborns preferred to look at the self-propelled motion event compared to the inert event; the binomial test did not reveal any statistically significant effect (binomial test, p = .39, ns). The percentage of total fixation time newborns spent looking at the self-propelled motion event was not significantly above chance level of 50% (M = 54%, SD = 12), t(11) = 1, p = .31). With regard to the number of orientations, newborns did not look more frequently at the self-propelled motion event (M = 14.3, SD = 3.6) compared to the inert one (M = 14, SD = 6.3), t(11) = .25, p = .81, ns (Figure 2.5).

Finally, with regard to the duration of the first orientation, newborns did not look longer at the self-propelled motion event (M = 6.4 s, SD = 3.6) compared to the inert event (M = 6.4 s, SD = 4.2), t(11) = .03, p = .97, ns). In both test phases, 9 out of 12 newborns oriented first towards the self-propelled motion event, and the binomial test did not reveal any statistically significant effect (binomial tests, p = .15, ns).

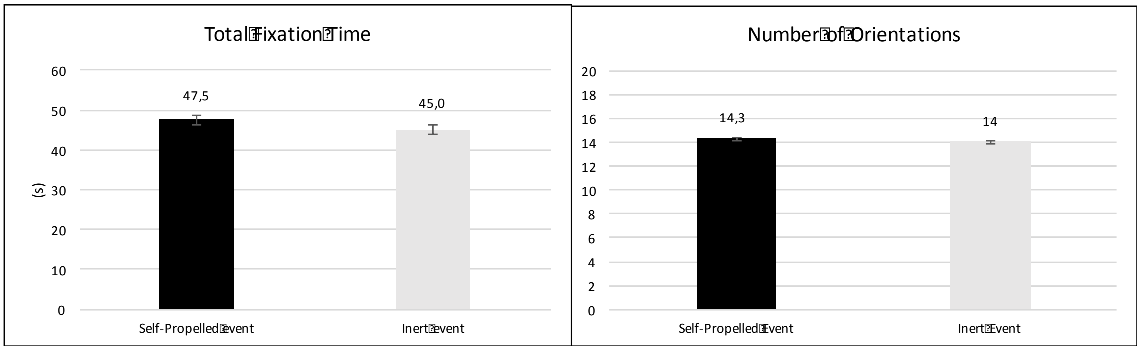

Figure 2.5 Average total fixation time (s) and number of orientations for the self-propelled motion and the inert events in Experiment 2.

Overall, Experiment 2 showed that newborns did not prefer the self-propelled motion event, where an object changes direction on its own without an external force, in contrast to an inert event in which the object changes its trajectory direction by contacting the occluder.

Experiment 2a: Change in Direction – Habituation Paradigm

Data from Experiment 2 showed that newborns did not prefer an object that changed its trajectory direction on its own, without contact with an external force. This result seems to suggest that when visual cues about the onset of motion of an object by self-produced motion were no longer available, newborns did not show any visual preference. However, this null result should be interpreted with caution, because it could be the case that the newborns simply were not able to discriminate between the two stimuli. Experiment 2a aimed at testing whether newborns were capable of discriminating, after habituation, the two stimuli presented in Experiment 2.

Participants

Seventeen healthy, full-term newborns took part in the experiment. Data from four babies were discarded because they changed their state during testing (n = 3) or because of position bias (n = 1); therefore, the final sample consisted of 13 newborns (10 males). Their postnatal age ranged from 12 to 120 h (M(age) = 57.9 h, SD = 38.6). All of them met the screening criteria of normal delivery, had a birth weight between 2510 and 4150g (M = 3245 g, SD = 630), and had an Apgar score of 10 at 5 min.

Apparatus and Procedure

The apparatus was the same as in the two previous experiments. Regarding the procedure, the experiment was carried out using an infant-control habituation setup (Horowitz, Paden, Bhana & Self, 1972). Infants were judged to have habituated when, from the fourth fixation onward, the sum of any three consecutive fixations was 50% or less of the total of the first three fixations (Slater, Earle, Morison & Rose, 1985). Half of the newborns habituated to the self-propelled motion event (i.e. the object that changed its trajectory direction without contact with an occluder), whereas the other half habituated to the inert event (i.e. the object that changed its trajectory direction after contacting an occluder). During the habituation phase, the same stimuli were presented side-by-side. The stimuli remained on the screen until the habituation criterion was reached. The habituation phase was followed by two preference tests in which a familiar event and a novel one were presented side-by-side. The left– right position of the stimuli was reversed from the first to the second presentation. Looking at one stimulus, generally the novel one, for a longer period of time indicated discrimination and recognition. During the preference test phase, the experimenter recorded the duration of the infant’ s fixation on each stimulus. The presentation lasted until the infant had fixated on each stimulus on least once and a total of 20 s of looking had been accumulated.

Stimuli

Stimuli were the same employed in Experiment 2.

Results

All newborns reached the habituation criterion. A oneway analysis of variance was run to compare the total fixation times to reach the habituation criterion for the two groups of subjects that had habituated to the self-propelled motion event (M = 51.2 s, SD = 13) or the inert event (M = 43.7 s, SD = 14.8). The results of the comparison were not significant, F(1,12) = .93, p = .36, ns. To test whether newborns were able to recognize and discriminate between the novel stimulus and the familiar one, a novelty preference score (percentage) was computed. The time that each infant spent looking at the novel stimulus during the two test presentations was divided by the total time spent looking at both test stimuli during the two presentations, and subsequently converted into a percentage score. Hence, only scores that were significantly above 50% indicated a preference for the novel stimulus. The mean novelty preference score was 58% (SD = 11.3), which differed significantly from the chance level of 50%, t(13) = 2.4, p = .031 (Cohen' s d = .68) (Figure 2.6).

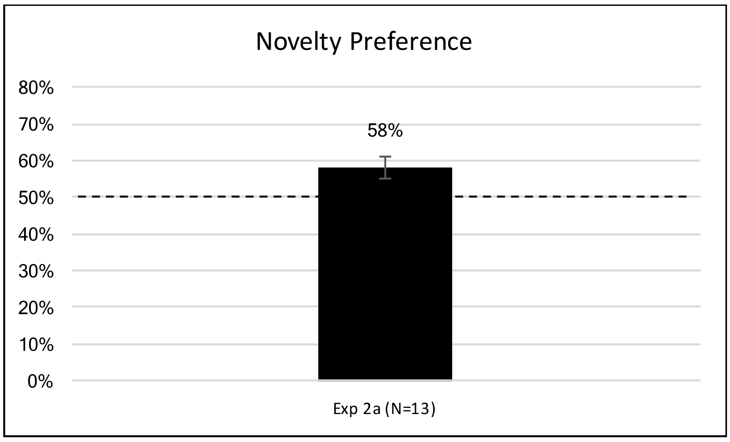

Figure 2.6 Average novelty preference in Experiment 2a.

Overall, these results do not support the assumption that the lack of preference found in Experiment 2a was due to an inability to discriminate between the two stimuli. Newborns were sensitive to differences between the two stimuli and, therefore, were able to discriminate and recognize the familiarized stimulus.

Experiments 3-4-5-6: Speed Changes

The aim of this second series of experiments was to test the presence of an inborn sensitivity to a visual cue of motion that in adults triggers animacy perception such as speed changes (i.e. acceleration and deceleration). In four different experiments (3, 4, 5, 6) newborns were tested with a visual preference paradigm. In Experiment 3 and 4, a single speed changes (acceleration, Experiment 3; deceleration, Experiment 4) were tested using a visual preference paradigm compared to an object that moves with a constant speed. In addition, to test the additive value of speed changes motion cue in Experiment 5 acceleration and deceleration was combined. In Experiment 5, the speed changes event was an object that enter in the screen and it moves along and horizontal trajectory and after a third of the trajectory suddenly accelerates and then decelerated returning to the initial speed. As demonstrated in Rosa-Salva and colleagues' study (2016) with chicks in the present experiment newborns were tested with a single object that suddenly change its speed compare to an object that moves with constant speed. If newborns are sensitive to speed changes, then they should prefer the event in which the object suddenly change its speed rather than the object that move with constant speed.

Moreover, to test if order of presentation of two speed changes have effect on animacy perception as demonstrated in adults (Gyulai, 2004), in Experiment 6, the speed changes were presented with inverted sequence of presentation compared to stimuli employed in Experiment 5. Whether the order of presentation have play a role on animacy perception since birth, newborns have to show a different pattern of results in Experiments 5 and 6.

Also in these two last experiments, the speed changes event was compared to an object that moves with a constant speed.

Experiment 3: Speed Change - Single acceleration - Visual Preference Paradigm

As well as the onset of motion by self-propulsion, speed changes are important visual cues in triggering animacy perception in both adults (Tremoulet & Feldman, 2000) and chicks (Rosa-Salva et al., 2016). In Experiment 3, newborns were presented with two computer-generated events in which the speed of an object was manipulated (i.e. accelerated vs. constant). In the accelerated event the object after a third of its own trajectory suddenly accelerates and continued its trajectory with accelerated motion patter. In contrast, in the constant event the object keep its initial speed along all its trajectory. If newborns are sensitive to speed changes motion cues, then they should prefer the event in which the object suddenly accelerates rather than the event in which the object keep constant speed.

Participants

Thirteen (4 males) full-term newborns took part at the experiment 3. Only one participant was discarded from the final sample because it showed a position bias. The final sample was of 12 newborns (1 males). Their postnatal age ranged from 13 to 144 h (M(age) = 55 h, SD = 43). All subjects met the normal delivery screening criteria, had a birth weight between 2600 and 3930 g (M = 3421 g, SD = 406), and had an Apgar score of 9 at 5 min. Newborns were tested only if awake and in an alert state, and after the parents had provided informed consent. All experimental procedures have been licensed by the Paediatric Clinic of the University of Padova.

Apparatus and Procedure

The apparatus and the procedure were the same used in experiment 1. The mean estimated reliability between coders was Pearson’ s r = .95, p < .02.

Stimuli

Stimuli consisted of two animation events presented on a computer screen: an accelerated motion event and a linear motion event. Unlike the previous experiments in these stimuli no occluders are present. In both event, the entrance of the objects was ambiguous, and the object appeared already in motion emerging from the external limit of the white background. After the entrance, the object continued to move towards the center of the screen and, at the end, it disappeared. In the acceleration motion event the object suddenly accelerated its speed at one third (5.3 cm, 10.02°) of the distance (16 cm, 28.07°). The speed change from 1.76 cm/s to 3.2 cm/s. In contrast in the linear motion event the object cover the same distance (16 cm) at a constant speed of 2.6 cm/s. Both events described lasted 6 s (150 frames, 25 frames/s). Videos were produced by looping the animations (Figure 2.7).

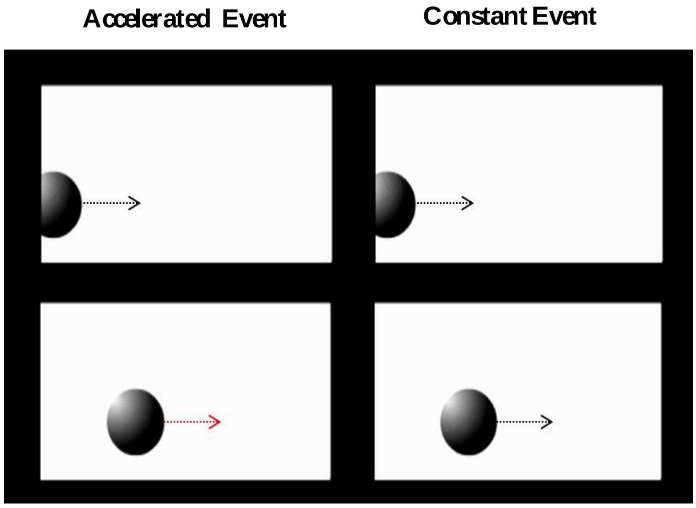

Figure 2.7 Schematic representation of stimuli employed in Experiment 3. On the left column, the accelerated event; on the right column, the constant event. The red arrow indicates a change of speed

Results

Since data were normally distributed as indicated by the Kolmogorov-Smirnov goodness-of-fit test, separate two-tailed dependent samples t-tests were performed. Newborns did not look significantly longer at the accelerated event (M = 62.49 s, SD = 15.3) compared to the constant event (M = 72.63 s, SD = 24), t(11) = - 1.092, p = .298, ns). Seven out of 12 newborns preferred to look at the accelerated motion event compared to the constant event; the binomial test did not reveal any statistically significant effect (binomial test, p = .77, ns). The percentage of total fixation time newborns spent looking at the accelerated event was not significantly above chance level of 50% (M = 48%, SD = 13), t(11) = -.66, p = .52). With regard to the number of orientations, newborns did not look more frequently at the accelerated event (M = 17, SD = 5.6) compared to the constant one (M = 17, SD = 6.9), t(11) = .29, p = .77, ns . Finally, with regard to the duration of the first orientation, newborns did not look longer at the accelerated event (M = 10.26 s, SD = 8.5) compared to the constant event (M = 12.95 s, SD = 12.9), t(11) = .57, p = .57, ns) (Figure 2.8).

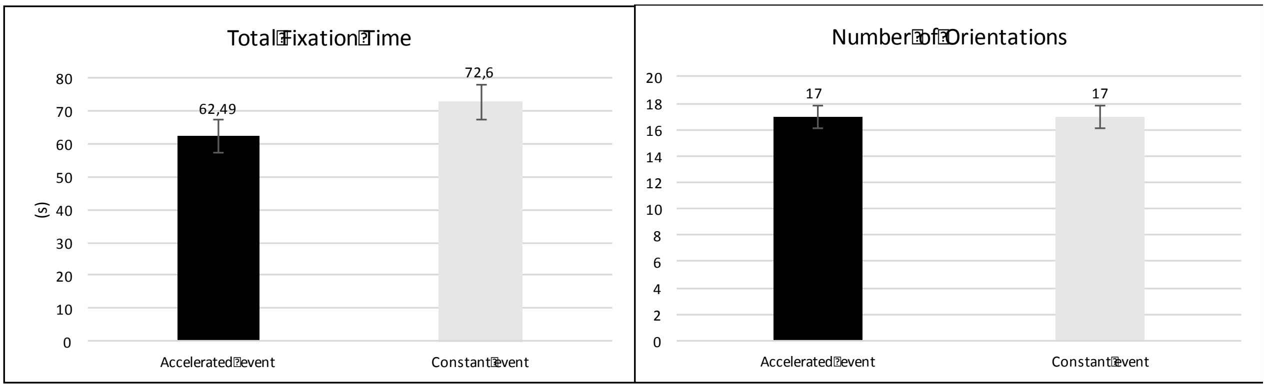

Figure 2.8 Average total fixation time (s) and number of orientations for the self-propelled motion and the inert events in Experiment 3.

Overall, Experiment 3 showed that newborns did not prefer the accelerated motion event, where an object suddenly accelerates rather than the constant event in which the object keeps the same speed along its trajectory.

Experiment 4: Speed Change – Single Deceleration – Visual Preference Paradigm

Data of Experiment 3 revealed that newborns did not prefer an object that suddenly accelerates rather than an object that moves with constant speed. It might plausible to hypothesized that a single speed change in acceleration is not easy to be detected to newborns’ visual system and for this reason newborns did not show a preference because they did not perceive a difference between the two events. Speed changes in terms of deceleration it might be easier to be detected by newborns' visual system; for this reason, in Experiment 4, a different sample of newborns were presented with an object that suddenly decelerate, instead accelerate, compared to an object that moves with a constant speed.

Participants

Seventeen (10 males) full-term newborns took part at the experiment 4. 6 were discarded from the final sample because they changed their state during testing (n=3) or showed a position bias (n=3). The final sample was of 11 newborns (8 males). Their postnatal age ranged from 12 to 50 h (M(age) = 29 h, SD = 13). All subjects met the normal delivery screening criteria, had a birth weight between 2440 and 4040 g (M = 3379 g, SD = 509), and had an Apgar score of 9 at 5 min. Newborns were tested only if awake and in an alert state, and after the parents had provided informed consent. All experimental procedures have been licensed by the Paediatric Clinic of the University of Padova.

Apparatus and Procedure

The apparatus and the procedure were the same used in Experiment 1. The mean estimated reliability between coders was Pearson' s $r = .86$, $p = .03$.

Stimuli

Stimuli consisted of two animation events presented on a computer screen: a decelerated motion event and a linear motion event. From a pictorial point of view, the stimuli were identical to the stimuli used in experiment 3. Unlike the stimuli used in the previous experiment, in deceleration motion event, the object suddenly decelerated its speed at one third (5.3 cm, 10.02°) of the distance (16 cm, 28.07°). The speed change from 3.2 cm/s to 1.76 cm/s. In contrast in the linear motion event the object cover the same distance (16 cm) at a constant speed of 2 cm/s. Both events described lasted 7.5 s (188 frames, 25 frames/s). Videos were produced by looping the animations.

Results

The Kolmogorov-Smirnov goodness-of-fit test showed that the data were normally distributed. To establish whether the newborns showed a spontaneous visual preference for one of the two stimuli, separate two-tailed dependent samples t -tests were performed. When tested for their preference for a decelerated event vs. an constant motion event, newborns did not look significantly longer at the decelerated event (M = 51.23 s, SD = 21.6) compared to the constant event (M = 54.41 s, SD = 20.92), t(10) = -4.88, p = .636, ns). Four out of 11 newborns preferred to look at the decelerated motion event compared to the constant event; the binomial test did not reveal any statistically significant effect (binomial test, p = .549, ns). The percentage of total fixation time newborns spent looking at the decelerated motion event was not significantly above chance level of 50% (M = 49%, SD = 11), t(10) = -.197, p = .848). With regard to the number of orientations, newborns did not look more frequently at the decelerated event (M = 13, SD = 4.2) compared to the constant one (M = 13, SD = 5.2), t(10) = -.327, p = .75, ns . Finally, with regard to the duration of the first orientation, newborns did not look longer at the decelerated event (M = 8.29 s, SD = 6.48) compared to the constant event (M = 8.29 s, SD = 5.26), t(10) = .000, p = 1.00, ns) (Figure 2.9).

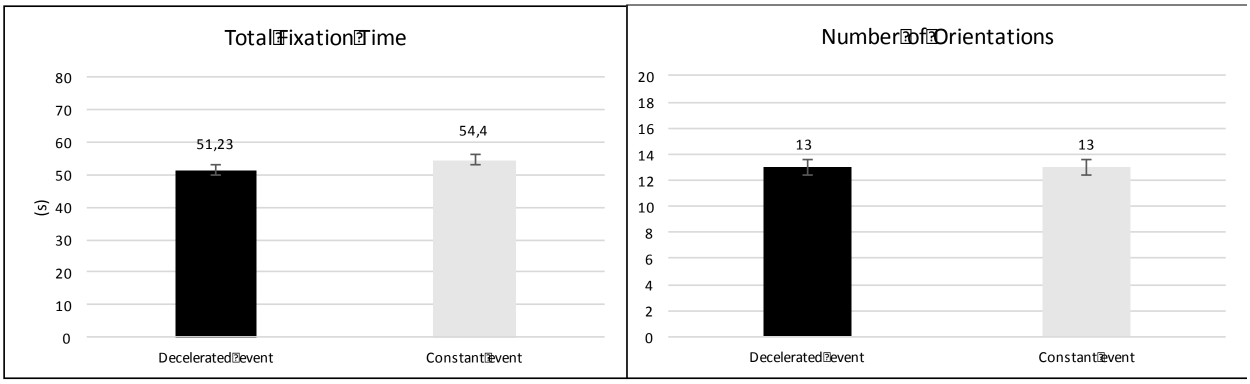

Figure 2.9 Average total fixation time (s) and number of orientations for the self-propelledmotion and the inert events in Experiment 4.

Overall, results of Experiment 4 seem to suggest that even a single speed change in term of deceleration is not sufficient for newborns to prefer a stimulus that change its speed rather than a stimulus in which the object keeps it speed constant.

Experiment 5: Speed Change – Acceleration - Deceleration pattern – Visual Preference Paradigm

Results of Experiment 3 and 4, showed newborns did not show any spontaneous preference for speed changes motion cues, in terms of acceleration and deceleration when they are presented singularly. However, in previous studies did with chicks and humans adults (Gyulai, 2004; Rosa-Salva et al., 2016) speed changes (i.e. acceleration and deceleration) were presented combined and it might be that speed changes as well other cues of motion, have an additive value in animacy perception. In this light, in Experiment 5, acceleration and deceleration were combined. Newborns were presented with two computer-generated events in which the speed of an object was manipulated (i.e. accelerated-decelerated vs. constant event). In the accelerated-decelerated (AD) event, the object at one third of its trajectory suddenly accelerates and after another third decelerates, returning to its original speed. In contrast, also in this experiment, in the constant event the object keeps constant its speed along its trajectory.

If speed changes have an additive value since birth also in human species, newborns have to show a preference for the object that moves according to the accelerated-decelerated pattern rather than the object that moves with constant speed.

Participants

Seventeen (12 males) full-term newborns took part at the Experiment 5. 4 were discarded from the final sample because they changed their state during testing (n=3) or showed a position bias (n=1). The final sample was of 13 newborns (11 males). Their postnatal age ranged from 12 to 144 h (M(age) = 63 h, SD = 35). All subjects met the normal delivery screening criteria, had a birth weight between 2510 and 3975 g (M = 3235 g, SD = 406), and had an Apgar score of 10 at 5 min. Newborns were tested only if awake and in an alert state, and after the parents had provided informed consent. All experimental procedures have been licensed by the Paediatric Clinic of the University of Padova.

Apparatus and Procedure

The apparatus and the procedure were the same used in experiment 1. The mean estimated reliability between coders was Pearson’ s r = .90, p = .02.

Stimuli

Stimuli consisted of two animation events presented on a computer screen: an accelerated-decelerated motion event and a constant motion event. From a pictorial point of view, the stimuli were identical to the stimuli used in experiment 3 and 4. Unlike the stimuli used in the previous experiments, in acceleration-deceleration motion event, the object suddenly accelerated, its speed at one third (5.3 cm, 10.02°) of the distance (16 cm, 28.07°) and then decelerated. The speed change from 1.76 cm/s to 3.2 cm/s and then 1.76 cm/s. In contrast in the linear motion event the object cover the same distance (16 cm) at a constant speed of 2 cm/s. Both events described lasted 8 s (200 frames, 25 frames/s). Videos were produced by looping the animations (Figure 2.10).

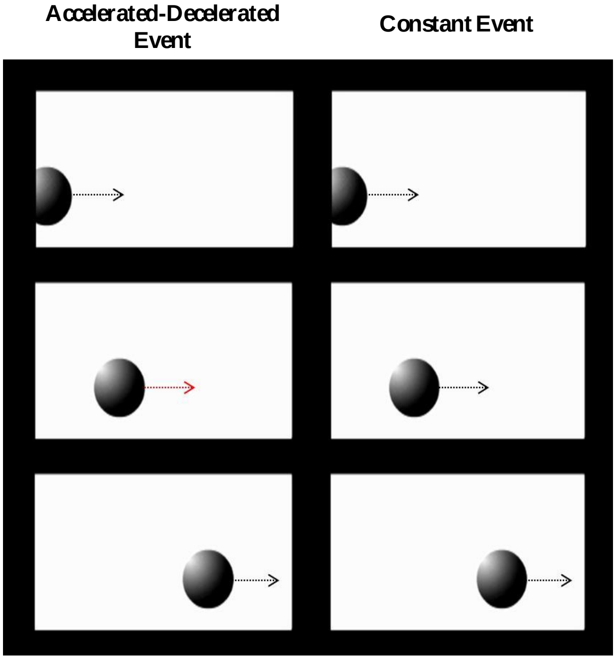

Figure 2.10 Schematic representation of stimuli employed in Experiment 5. On the left column, the accelerated-decelerated event; on the right column, the constant event. The red arrow indicates a change of speed. After two third of the trajectory the object in the accelerated-decelerated event returns to its original speed.

Results

Since data were normally distributed as indicated by the Kolmogorov-Smirnov goodness-of-fit test, separate two-tailed dependent samples t-tests were performed. Newborns looked significantly longer at the accelerated-decelerated event (M = 51.11 s, SD = 22.3) compared to the constant event (M = 38.34 s, SD = 10), t(12) = 2.85, p

= .014). Eleven out of 13 newborns preferred to look at the accelerated-decelerated motion event compared to the constant event; the binomial test revealed statistically significant effect (binomial test, p = .022). The percentage of total fixation time newborns spent looking at the accelerated event was significantly above chance level of 50% (M = 55%, SD = 7), t(12) = 2.403, p = .033). With regard to the number of orientations, newborns did not look more frequently at the accelerated-decelerated event (M = 15, SD = 6.8) compared to the constant one (M = 16, SD = 5.3), t(12) = -.44, p = .665, ns. Finally, with regard to the duration of the first orientation, newborns did not look longer at the accelerated-decelerated event (M = 5.36 s, SD = 4.02) compared to the constant event (M = 6.4 s, SD = 2.8), t(12) = -.809, p = .43, ns) (Figure 2.11).

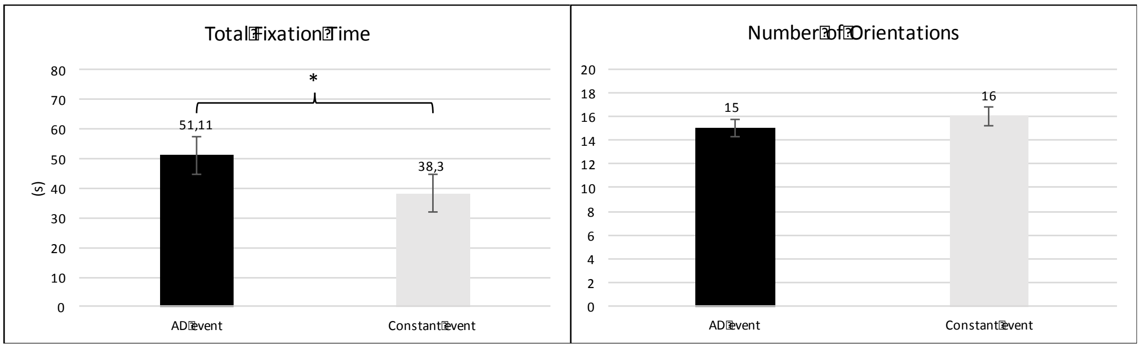

Figure 2.11 Average total fixation time (s) and number of orientations for the self-propelled motion and the ambiguous events in Experiment 5. Significant differences (*p* < .05) are marked with "*"

Overall, Experiment 5 showed that newborns prefer an object that change its speed according to AD pattern of motion compared to an object that keeps constant its speed. These results seem to suggest that event in newborns speed changes have an additive value in animacy perception. Indeed, when speed changes were presented singularly, newborns did not show any preference (Experiments 3 and 4).

Experiment 6: Speed Change – Deceleration-Acceleration pattern – Visual Preference Paradigm

The aim of Experiment 6, was to test if the order of presentation of speed changes is a crucial perceptual feature also in newborns. Previous study that tested adults, revealed that adults rate as more animate an object that moves according to AD pattern rather than an object that moves with deceleration-acceleration pattern (DA; Gyulai, 2004). In this light, in Experiment 6 newborns were presented with the same stimuli of the previous experiment but the order of speed changes was inverted. If the order of presentation of speed changes have a role also in newborns' perception it might be plausible hypothesized that in this experiment newborns might does not show a preference for the object that suddenly decelerate and then accelerate.

Participants

Fourteen (6 males) full-term newborns took part at the Experiment 6. Two newborns were discarded from the final sample because they changed their state during testing. The final sample was of 12 newborns (6 males). Their postnatal age ranged from 12 to 76 h (M(age) = 39 h, SD = 22). All subjects met the normal delivery screening criteria, had a birth weight between 2540 and 4105 g (M = 3276 g, SD = 489), and had an Apgar score of 10 at 5 min. Newborns were tested only if awake and in an alert state, and after the parents had provided informed consent. All experimental procedures have been licensed by the Paediatric Clinic of the University of Padova.

Apparatus and Procedure

The apparatus and the procedure were the same used in experiment 1. The mean estimated reliability between coders was Pearson' s r = .89, p = .03.

Stimuli

Stimuli consisted of two animation events presented on a computer screen: a decelerated-decelerated motion event and a constant motion event. From a pictorial point of view, the stimuli were identical to the stimuli used in experiment 5. Unlike the stimuli used in the previous experiments, in deceleration-acceleration motion event, the object suddenly decelerated, its speed at one third (5.3 cm, 10.02°) of the distance (16 cm, 28.07°) and then decelerated. The speed change from 3.2 cm/s to 1.76 cm/s and then 3.2 cm/s. In contrast in the linear motion event the object cover the same distance (16 cm) at a constant speed of 2.4 cm/s. Both events described lasted 6.5 s (163 frames, 25 frames/s). Videos were produced by looping the animations.

Results

The Kolmogorov-Smirnov goodness-of-fit test showed that the data were normally distributed. To establish whether the newborns showed a spontaneous visual preference for one of the two stimuli, separate two-tailed dependent samples t -tests were performed. When tested for their preference for a decelerated-accelerated event vs. an constant motion event, newborns did not look significantly longer at the decelerated-accelerated event (M = 49.71 s, SD = 28.6) compared to the constant event (M = 49.03 s, SD = 27.26), t(11) = - 0.67, p = .948, ns). Four out of 12 newborns preferred to look at the decelerated motion event compared to the constant event; the binomial test did not reveal any statistically significant effect (binomial test, p = .38, ns). The percentage of total fixation time newborns spent looking at the decelerated-accelerated motion event was not significantly above chance level of 50% (M = 49%, SD = 12), t(11) = -137, p = .894). Finally, with regard to the number of orientations, newborns did not look more frequently at the decelerated-accelerated event (M = 13, SD = 4.9) compared to the constant one (M = 13, SD = 4.6), t(11) = -.261, p = .79, ns (Figure 2.12).

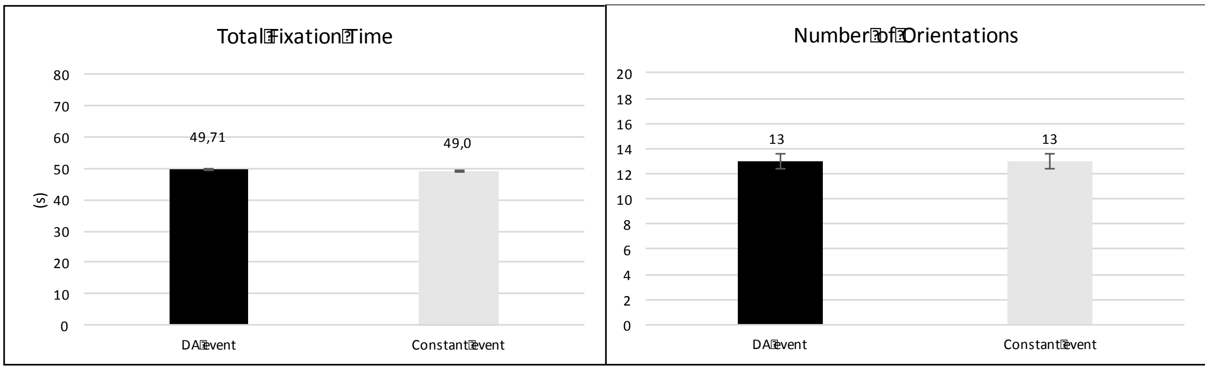

Figure 2.12 Average total fixation time (s) and number of orientations for the self-propelledmotion and the ambiguous events in Experiment 6.

Overall, Experiment 7 demonstrates newborns did not show a preference for DA event compared to a constant event. This result, seems to suggest that the order of presentation of speed changes motion cues is a crucial perceptual feature also in newborns' perception.

Taken together, results obtained from Experiment 3, 4, 5, and 6, demonstrate that also newborns are sensitive to speed change motion cues. Specifically, results of the experiments that tested newborns' preference for speed changes demonstrated that newborns are not sensitive to speed changes in general but their attention is specifically attracted by the combination of acceleration and deceleration and only when these cues of motion follow a specific order of presentation. Newborns seem to have an innate predisposition towards acceleration-deceleration pattern of kinematics (Experiment 5), and they do not have a bias towards single speed changes (Experiments 3, and 4) or when the order of presentation was inverted (Experiment 6).

Conclusions

The aim of the present Chapter was to systematically test to which motion cues, that trigger animacy perception in adults, newborns are sensitive.

Overall, results demonstrate that newborns are sensitive to the major motion cues such as self-propulsion, change in direction and change in speed and data of these experiments also demonstrate that speed changes cues must be presented together and in a precise order (i.e. acceleration must precede deceleration).

Specifically, Experiment 1 demonstrated that newborns preferred a self-propelled motion event compared to an ambiguous event in which no explicit visual cues about the motion onset of the object were available (i.e. the entrance of the object on the screen was masked or ambiguous due to the presence of an occluder). This result seems to suggest that an object that starts to move on its own attracts newborns' visual attention. However, one might argue that the preference for a self-propelled motion event is a novelty response that comes from the sudden onset of motion and not from an appreciation of self-propulsion per se. Indeed, the possibility that sudden onset of motion per se is a more interesting display for newborns makes sense. However, newborns did not look more frequently at the exact time when the object started to move in the self-propelled motion event, demonstrating that the sudden onset motion per se did not grab newborns' attention. Moreover, a second alternative explanation for the significant effect of Experiment 1 might be that newborns manifest a preference for a disappearance event over an object appearance event. This possible explanation can be discarded because newborns did not look more frequently at the object that disappeared behind the occluder in the self-propelled display during the end of the event, as documented by the percentage of the number of orientations toward the disappearing object that was the not above chance level.

In Experiment 2, the entrance of the object on the screen was masked in both events, so no cues for the onset of motion were available, but only in the self-propelled motion event did the object changed its trajectory direction on its own without external force and external contact. The results from Experiment 2 demonstrated that newborns, even if they were able to discriminate between the two events, as shown in Experiment 2, did not manifest any preference for the event in which the object changed its trajectory direction without external contact (i.e. self-propelled motion event) compared to an event where the object changed its trajectory direction only after an external contact with the obstacle (i.e. inert condition). It is worth pointing out that by 7 months of age, infants already associate change in direction and speed with animals (Träuble et al., 2014). However, in that study 7-month-old infants, that are older than newborns and with more visual experience of animate and inanimate objects, were presented with stimuli that changed both their direction and speed, while in study newborns were presented with only one specific visual cue of motion, which is trajectory direction change. It is plausible that different visual cues of motion together could have additive effects on animacy perception at birth.

In Experiments 3, 4, 5, and 6, an object that changes in speed seems to attract newborns' attention compared to an object that moves with constant speed. However, in Experiment 3 and 4, the lack of visual preference in both experiment seems to suggest that only a single speed change, either acceleration or deceleration, seems to not be a sufficient cue of motion that could elicit a visual preference in human newborns. More intriguing, newborns did not prefer the object that move with constant speed neither even if, the constant speed object it should be easier to follow for newborns' visual system (Johnson, 2011). As well as for change in direction, a single change in speed is not sufficient to elicit a visual preference.

However, in experiment 5 and 6, two speed changes occur in the same stimulus. In experiment 5, newborns showed a visual preference for the object that suddenly accelerated and then decelerated compared to the same object that moves without any speed changes. The results of the experiment 6, instead demonstrate that the when a deceleration precedes an acceleration newborns did not prefer the events with speed changes or the constant event neither. Overall, the results of the Experiment 3, 4, 5 and 6, suggest that newborns have some rudimentary attentional bias toward speed changes but they need to have sufficient information (e.g. two changes instead of one) and the sequence of the presentation of changes is important.

The acceleration-deceleration (AD) pattern seems to be the most attractive combination of speed changes. It might be plausible to hypotheses that newborns manifest a preference only in this case because the AD pattern is the kinematic pattern that characterize biological motion and goal-directed actions (Fox & McDaniel, 1982; Troje, 2013). Specifically, when a human being starts to walk or to grasp an object, the foot or the hand, at the beginning accelerate and only when it approaches to an object or in proximity of a surface, decelerates.

Overall the results of these six experiments support the view that several vertebrate species, including humans, have a primitive bias toward detecting social agents and attending to and preferentially processing sensory information about other living entities (Carey, 2009) such as motion. This evidence supports the idea that vertebrates, comprising phylogenetically distant species such as domestic fowls and humans, have primitive neural pathways that ensure a bias to preferentially attend to and process sensory information about other living entities, as in the case of face and biological motion perception (Rosa-Salva, Farroni, Regolin, Vallortigara & Johnson, 2011; Rosa-Salva, Mayer & Vallortigara, 2015; Rosa-Salva, Regolin & Vallortigara, 2012; Simion, Di Giorgio, Leo & Bardi, 2011).

Additionally, the results of the experiment presented in this Chapter support also the idea that animacy perception might be considered as a result of some low-level processes of the visual system (Rutherford, 2013). However, the newborns' sensitivity to detect visual cues of motion that belongs to animate and not to inanimate things, does not imply that newborns possess abstract concepts of animacy or agency (Carey, 2009). The evidence that I found, suggests that since birth we have attentional biases that are pre-wired to detect specific cues of motion that belong to animate entities, such as self-propulsion and AD pattern of motion. The sensitivity to perceptual cues of motion might be a sort of bootstrapping point to the development of the ability of adults and infants to extract social information from motion. As postulates by Carey (2009) the perceptual cues of motion, that trigger animacy perception in adults are the building blocks on which during development, infants built the abstract concepts of intentional agency (i.e. the precocious capacity to interpret the behavior of animate objects in terms of goals and motivational states) and mentalistic agency (i.e. mental states such as desires and beliefs). In the same vein, Leslie (1994; Biro & Leslie 2007) states that the perception of low-level visual cues of motion are the starting point on which humans build their high-order cognitive processes (namely mentalizing), such as for example attribution of propositional attitudes, such as beliefs and desires.

Taken together results of the six experiments presented, suggest that newborns have some attentional biases towards cues of motion such as self-propulsion and AD pattern of motion. These biases allow the system to focus attention towards these specific cues of motion also when they are embedded in complex arrays.

Nevertheless, percepts of animacy may also be driven by more specific type of motion cues, such as when the relative motion of many points in point-light displays are perceived in terms of particular forms of vertebrates' motion (Scholl & Gao, 2013). In light of this, in chapter 3, the visual cues of motion that trigger animacy perception were presented in a complex array of dots depicting a walking human figure to test if infants and adults, can use these visual cues of motion to extract social relevant information, such as directionality, from a complex array of dots. Moreover, the second aim of the Chapter 3 is also to test if directionality can trigger orienting of visuo-spatial attention both in infants and adults.

Chapter 3

Visuo-Spatial orienting triggered by biological motion walking direction: a developmental trajectory

Introduction

As describe in Chapter 2, newborns are sensitive to motion cues that elicit animacy perception in adults. The results described in the previous chapter suggest that the visual system possesses some biases towards certain features of motion of animate entities, such as self-propulsion and acceleration-deceleration patterns Detection of animacy may also be driven by more specific types of motions cues, such as when the relative motion of many dots in a complex point light display are organized and perceived as a particular form of vertebrates' motion such as a human walker, (Johansson, 1973; Scholl & Gao 2013). Specifically, in a complex array of dots, each single dot has self-propelled motion and follows the acceleration and deceleration pattern of motion. When these cues of motion are applied to dots that composed complex arrays, adults are able to extract, simply analyzing motion, a lot of social information. Moreover, it has been demonstrated that motion of local dots, particularly dots depicting feet, conveyed information such as directionality even if no translation is occurring and adults can use this information to orient attention towards the surrounding space (Shi, Weng, He, Jiang, 2010).

Considering this literature, the aim of the present chapter is to examine the ability of infants to extract directionality from complex arrays of dots, and to test how the information of directionality can trigger infants' attention toward the surrounding space and whether or not there are beneficial effects at a neural level. In the first section, the literature and the theoretical models on perception of biological motion in adults and infants will be described along with studies that investigated the role of biological motion walking direction in inducing visuo-spatial orienting. In the second section two different experiments will be presented to test whether 3- and 6-month old infants extract information of directionality conveyed by a complex array of dots, such as a PLD depicting a walking human figure, and conveyed by cues of motion such as self-propulsion and AD pattern of motion, can trigger orienting of attention in infancy. The two experiments with infants of two different age levels, were aimed at investigating the neural correlates associated with the possible visuo-spatial orienting triggered by biological motion. To this aim high density event related evoked potential responses (ERPs) were recorded. An additional control group of adults was tested (Experiment 9) to investigates which are the neural correlates associated with the attentional orienting triggered by biological motion in the adult specialized system.

3.1 Complex arrays of moving dots in adults: The case of biological motion.

Motion of living beings, particularly vertebrates, is peculiar. When vertebrate moves, its limbs and torso undergo a specific pattern of motion constrained by the skeletal structure supporting the body. As results, spatial relation between some parts of the body remained invariants (i.e. distances between joints of the limbs), whereas spatial relation between other parts continuously change across the movement. Importantly, vertebrates' motion has specific constrains also from a kinematic point of view. For example, when vertebrates walk, the pattern of motion of each single step has an accelerated-decelerated sequence. The acceleration phase preceded the deceleration at the beginning of each step (e.g. when the foot starts moving). On the other hand, deceleration is at the end of the action, when the body parts are approaching a surface. (Figure 3.1).

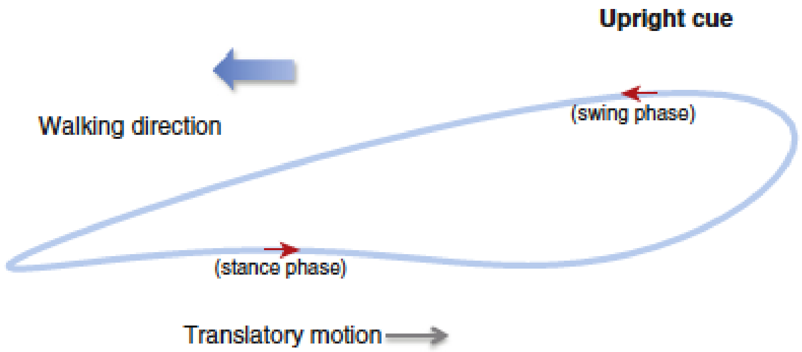

Figure 3.1 Schematic representation of the trajectory of walking. The swing phase is characterized by an acceleration at the beginning and by a deceleration when the stance phase occurs.

The best way to study humans' sensitivity towards motion, is to remove all pictorial information and to use only a dozen of dots, representing the major joints of vertebrates' skeleton, that are moving according to the physical constrained of the body structure (point-light display, PLD). The first study that employed PLDs stimuli was done by Johansson (1973) to test if the human visual system applied some strategies to carry out an organization of a PLD depicted a human figure (structure from motion). Applying *vector analysis*' model, Johansson assumed that human adults' visual system can decompose motion in two different components related by a hierarchical relation: common motion and relative motion. Common motion refers to the information that can be retrieved from the global configuration of the complex array. On the contrary, relative motion refers to the analysis linked to local motion of each single element that constitutes the array. Results of Johansson's study demonstrated that adults, only seeing a dozen of dots can organize them in a human figure only after 100/200 ms of exposure.

Moreover, in a second study, Johansson also discovered that with an exposure of 400 ms, adults are able to discriminate and recognize the type of action the PLD is representing (Johansson, 1976). With these pioneering studies, Johansson shed light on adults’ ability to extract structure from motion only by looking at moving dots. In other words, adults, just viewing a dozen of dots that move together, can organize them into a coherent figure and they can distinguish and recognize the action that the PLD.

Explanations of how observers extract form and action from these displays fall into two different classes: event-from-form and event-from-dynamics theories. Event-from-form explanations suggest that visual processes first extract form, or parts of the form, and then determine the action. On the contrary, the event-from-dynamics approach is based on spatiotemporal information for action and argued that the most useful information is that about dynamics. (Shipley, 2003; Simion et al., 2008).

However, biological motion cannot be only confined to PLDs depicting human walkers. Mather and West (1993) demonstrated that people could identify animals, such as camel, goat, baboon, horse and elephant whose movement were represented by point-light displays.

In addition, Pollick and colleagues (2001) tested adults’ ability to perceive motion of a human gestures conveyed by the arms, such as knocking and drinking. The author presented PLDs of a single arm that performed action. In so doing, Pollick and colleagues (2001) extended the definition of biological motion as suggested by Johansson: biological motion is not only the ambulatory pattern of terrestrial bipeds and quadrupeds but also the motion of body parts in isolation. For this reason, the term biological motion is currently used in literature to refer to studies that have investigated movements of living organisms such as people or animals - both whole body motion as well as partial movements by feet, hands, head and eyes - to be studied by employing PLDs stimuli (Blake & Shiffrar, 2007; Moore, 2012).

3.2 Taxonomies of biological motion

Considering the heterogeneous *corpus* of studies that refer to biological motion, authors tried to classify different types of biological motion according to different aspects.

A first classification is proposed by Moore (2012), that classified biological motion according to the types of stimuli employed in the studies differentiating between biological, biomechanical and human motion. The term biological motion is the most general level of motion, and it can be used to cover all forms of motion shown by animals, with the most basic level of motion characterized by self-starting irregular, partially contingent motion. Biomechanical motion is a more specific aspect of biological motion that is associated with having articulated moving limbs. This motion is showed by humans and many, but not all, animals. According to this distinction studies that implied PLDs of walking hen or other types of animals refers to biomechanical motion. Human motion, is the more specific level of the taxonomy proposed by Moore, and it refer to motion that is peculiar of human beings. Although, human motion is biological and contains biomechanical movements, human motion has specific properties that are constrained by the human skeleton, such as arms and legs are vertically aligned.

Troje (2013) proposed a second taxonomy of biological motion. This classification is based on the differences between the experimental paradigms, the stimuli employed in the different research that tried, from Johansson till today, to investigate humans' ability to process humans (and animal) motion. The most general level of Troje' taxonomy is defined as life motion. Life motion refers to all the studies that used realistic and stylized stimuli to study visual life motion. The first distinction is between "realistic" and "stylized". Realistic level includes studies that used real stimuli, such as video, full computer animation or 3D avatars. The main problem with these stimuli is that kinematics information was not isolated for other social information such as faces. On the other hand, stylized is used to refer to all that studies that investigates kinematics index of human motion without any pictorial information. In light of this, at this level all studies that employed moving objects or complex arrays of dots were inserted. Stylized level is further differentiated between in Extrinsic and Intrinsic motion. Whilst, extrinsic motion is used to refer to studies that investigate animate motion and animacy perception elicit by motion of geometrical shapes (i.e. Heider and Simmel's study), intrinsic motion, instead, refers to biological motion as defined by Troje: "*biological motion is to use only to the study of the perception of intrinsic, deformable motion of animals and people by means of stimuli that are stylized in order to keep information conveyed by channels other than the kinematics of the body at minimum*" (Troje, 2013 p. 27). In this vein, studies that employed PLDs are put inside the intrinsic level of Troje's taxonomy. A further distinction of intrinsic motion is referring to the hierarchical nature of biological motion stimuli. Adults can retrieve information from biological motion analyzing two different levels of information: the global level and the local level of information. Global level refers to information that can be extracted from PLDs analyzing the configural information (i.e. Johansson' common motion); local level instead is used to refer to information that can be retrieved from analyzing the motion of each single dot (i.e. Johansson' relative motion; figure 3.2).

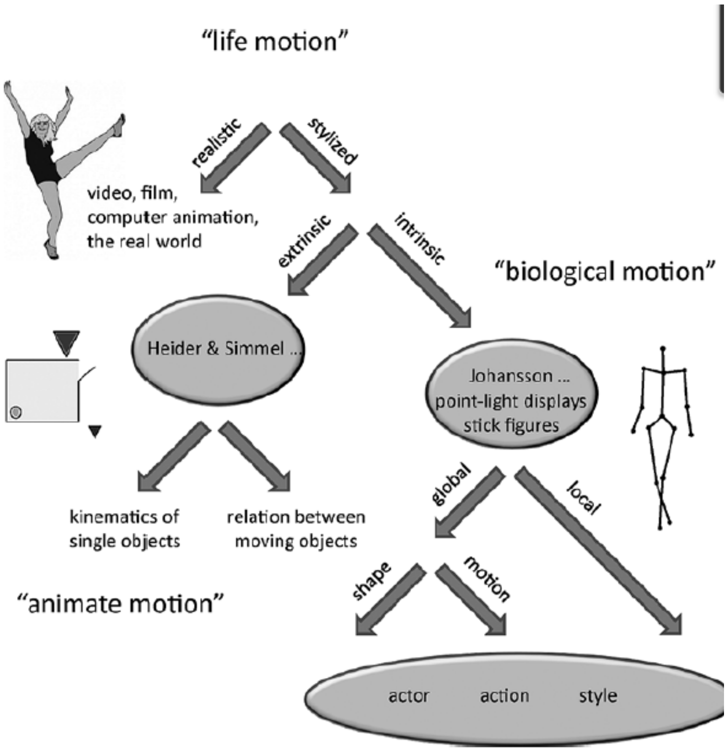

Figure 3.2 Schematic representation of Troje's taxonomy

Based on this two taxonomies in the following paragraphs studies that investigate biological motion perception in adults (3.3) and infants (3.5) will be describe.

3.3 Biological motion perception in human adults

Starting from Johansson' studies (1973, 1976) a huge amount of experiments investigates which social information adults can retrieve form a point-light display.

Data from empirical studies testing adults proved their ability to retrieve multiple sources of information from simple point-light displays depicting a human figure, from actions (Dittrich, 1993), to emotions (Dittrich, Troscianko, Lea, & Morgan, 1996) and gender (Kozlowski & Cutting, 1977). Importantly, this ability is observed as long as the stimuli are presented upright. Indeed, a decrease in recognition occurs when the stimuli are presented upside-down (Chang & Troje, 2009; Hirai, Chang, Saunders, & Troje, 2011; Pavlova & Sokolov, 2000; Sumi, 1984; Troje & Westhoff, 2006). The reduction in the ability to recognize biological motion in PLDs when are presented inverted it might be interpreted as evidence of an impaired processing of familiar shape of an articulated body (Sumi, 1984; Berthental & Pinto, 1994; Pavlova & Sokolov, 2000). The role of configural invariants for processing biological motion was tested employing masked PLDs (i.e. stimulus which is mask by superimposing it with scrambled walkers). Berthental and Pinto (1994), tested adults with a detection task employing mask coherent walker embedded in scrambled walkers presented upright and inverted. Results showed that detection of walker figure was impaired when the stimulus was presented inverted suggesting that perception of biological motion might be driven by the analysis of global level of information. However, when an inverted or upright human body walking on hands instead of feet is presented to participants, adults are less accurate at detecting the former, so that the orientation of local dots motion seems crucial for recognition (Shipley, 2003). Taken together this evidence sheds light to the hierarchical nature of biological motion stimuli. Indeed, recent studies are mainly interested to discover which social information an adult can retrieve from the global shape of PLDs, and to discover the relation between global and local levels of information. Due to its hierarchical nature, some cognitive models were aimed at explaining the nature of computations supporting biological motion processing in adults have been elaborated (Troje & Westoff, 2006; Johnson, 2006; Troje, 2008).

3.3.1 Local and global information: a multi-level model

As well as other hierarchical social stimuli, such as faces, some authors suggest that distinct mechanism would be at the bases of biological motion detection.

According to Troje and colleagues' model (Troje & Westhoff 2006; Chang & Troje, 2009), at the base of the ability to analyze and to extract social information from biological motion there would be two distinct mechanisms. The first one, namely Perceptual Life Detector, would be an ontogenetically innate mechanism supported by subcortical structure. This mechanism would be present since birth, and it would be deputed to be sensitive to the motion of legged vertebrate appearing in the visual periphery and walking direction (Jonhson, 2006). Indeed, the oscillating movement of dots representing feet, is the best motion cues to detect and discriminate the walking direction of an animal. The Perceptual Life Detector would be shared with other mammals and phylogenetically ancient because the survival of the individuals would depend on it. The main function of this mechanism would be to detect others and this detection would be based of motion of the legs, and more specifically on the local motion of feet (Troje & Westhoff, 2006).

On the other hand, the second mechanism, would not be an innate mechanism but an experience-dependent mechanism. The experience that the individuals have with conspecifics' motion, because the Perceptual Life Detector is always active during life, shaped this second, cortical mechanism. Whilst the first mechanism is deputed to detect others based on motion, the experience-dependent mechanism would be responsible to recognize and identifying agents based on configural information. Moreover, the extraction of relevant social information would be supported by this mechanism (Chang & Troje 2009), and this information might be used to interpret other intentions and depositions and moreover they might be used for specific tasks such as orienting attention.

3.4 Biological motion and orienting of attention in adults

3.4.1 Behavioral evidence

According to Troje and Johnson (Johnson, 2006; Troje & Westhoff 2006; Chang & Troje, 2009) the oscillating movement of dots representing feet, is the best motion cues to detect and discriminate the walking direction of an animal. In this vein, information of directionality can be retrieve from biological motion simply analyzing the local level of PLDs stimuli depicting a walking human, such as the pattern of motion of dots that represent the feet that move according to self-propulsion and AD pattern of motion (Hirai, Saunders & Troje, 2011).

Walking direction is an important attribute of biological motion, which provides critical information about another living creature's dispositions and intentions and consequently it might plausible to hypothesized that also walking direction as well other social stimuli (i.e. eye gaze) can trigger an orienting of attention. Adapting cueing paradigm (Posner, 1980) several studies tested the possibility that walking direction can trigger orienting of attention in adults (Shi et al., 2010; Hirai et al., 2011; Bardi, et al., 2015).

Orienting of spatial attention can be either overt, when it is accompanied by eye movements, or covert, when attention is deployed to relevant locations without eye movements (Posner, 1980). Several studies using a cueing paradigm have shown that, if a peripheral stimulus (i.e. the target) is preceded by a directional stimulus (i.e. the cue) that predicts the side of appearing of the following target, adults show faster reaction times to the target (i.e. the priming effect; Posner, 2016). Moreover, either overt and covert orienting of attention might be exogenous and endogenous: this distinction is related to the nature of processes and nature of stimuli employed during orienting of attention. Exogenous or bottom-up orienting of attention refers to the automatic, involuntary allocation of attention. On the contrary, endogenous or top-down orienting refers to the controlled, voluntary allocation of attention. The distinction is related also to the nature of stimuli employed as cue; generally exogenous cues are stimuli that need not be voluntary processed by participants, but they attract automatically attention (i.e. flash of light). Endogenous cues instead involved a voluntary process of cue such as, for example a word that indicates a precise spatial position (i.e. “left” or “right”; Posner 1980; Peelen, Heslenfeld, & Theeuwes, 2014; Posner 2016).

Walking direction, as well other social stimuli, such as eye gaze and body orientation, triggered orienting of attention toward peripheral space. Adults are faster and more accurate to respond to targets that appeared in a spatial position previously indicated by eye gaze direction (i.e. Friesen & Kingstone, 1998; Driver et al., 1999; Kingstone, Tipper, Ristic & Ngan, 2004; Hooker et al., 2003) and pictorial body structure (Gervais, Reed, Beall, & Roberts, 2010).

The first study that employed PLDs walking direction as a cue to test viuo-spatial orienting was carried out by Shi, Weng, He, & Jiang (2010). The authors recorded accuracy responses in a discrimination task. Results demonstrated that the walking direction of an upright point-light biological motion display induced an automatic shift of visuo-spatial attention in the observers. In this study, participants were asked to discriminate the orientation of a laterally presented gabor patch. The target was preceded by a point-light sequence depicting a human walker, an animal walker, a static human point-light figure or a rolling point-light circle. Findings revealed that, although participants were explicitly told that the direction of the cue was not predictive of the position of the target, accuracy in a discrimination task was significantly better when the position of the target was congruent with the facing direction of an upright walking human or animal cue than when it did not. Intriguing, no significant effect was found when the cue was a rolling point-light circle and when PLD of human walker was presented static. This result revealed that automatic orienting of attention can be elicited by upright biological motion walking direction. Moreover, in the study of Hirai, Saunders and colleagues (2011), the latency to make a saccade to a peripheral target was measured under condition in which the location of the target was congruent or incongruent with the facing direction of a centrally presented point-light walker (upright or inverted). Participants were asked to orient their eyes either toward the right or the left according to the color of the cue. Results revealed that saccade latency and accuracy were affected by the facing direction of the central walker and this was true only when the cue was presented upright. Another study, using a Simon effect task, Bosbach, Prinz, & Kerzel (2004), observed a stimulus–response compatibility effect with point-light walkers. In this task, participants were asked to respond to the color of the dots representing the walker. Although the walking direction of the point-light display was irrelevant for the task, responses were faster and less error prone when the facing direction of the walker and the response position corresponded than when they do not. Finally, an eye tracker study employing a cueing paradigm with a PLDs of human walkers as central cue, demonstrated that adults' saccade latencies are faster toward target that appeared in congruent spatial position with the walking direction also when adults were not informed on the nature of the PLDs stimuli (i.e. they were not informed that PLDs were human walkers). Moreover, also in this case, as well in Shi and colleagues' study, the congruency effect is present only when the PLDs were presented upright and not inverted (Bardi et al., 2015).

3.4.2 Electrophysiological evidence

As suggested by Posner (1980; 2016), orienting of attention toward a surrounding space have a direct effect on visual processing of stimuli that appear in that portion of space. In other words, the consequence of orienting of visuo-spatial attention is a more proficient (i.e. faster reaction times and higher accuracy) visual process for stimuli that are present in a certain portion of the space where attention is located. As demonstrated by behavioral studies, orienting of attention toward cued stimuli is coupled with a facilitation in reaction time and in an increasing of accuracy to respond to them. Moreover, the behavioral findings were complemented by ERP studies that showed that orienting of attention toward a target modulates the P1 and N1 sensory components, supporting the idea that orienting of attention had sensory consequences (Carrasco, 2011). Several studies employed cue paradigm (Posner, 1980) with social stimuli as cue and recorded ERP target locked components. Employing eye gaze as cue, Schuller and Rossion (2001; 2004), recorded ERPs target-locked responses to investigates the time-course of the visual processing modulated by these reflexive shifts of attention. Findings revealed an enhancement of occipito-parietal sensory components (i.e. P1 and N1) for congruent rather than incongruent targets. Specifically, occipital P1 (~110 ms) and occipito-parieto-temporal N1 (~150 ms) components were earlier and larger for congruent rather than incongruent targets. These results show that reflexive shifts of attention following eye gaze increase and speed up the processing of cued visual information. Moreover, these findings provide evidence that attention can rapidly modify the processing of visual information in extrastriate cortex. Additionally, Tipper and colleagues' study (2008) demonstrated that employing an ambiguous stimulus as cue ERP target locked responses were different in relation of the social relevance of the ambiguous stimulus. The authors used a geometrical shape of a triangles that could be interpreted either as an eye or the head of an arrow. Data indicate that although both eye gaze and arrow cues produced behavioral cueing effects, an attention-related sensory gain effect was present only for eye gaze cues. Specifically, also in this study the author found a greater amplitude of P1 component for congruent rather than incongruent targets only when the ambiguous cue were interpreted by participants as an eye. These results, seem to confirm that the social relevance of cue stimuli is particularly effective at highlighting sensory information being processed at the gazed-at location (Tipper, Handy, Giesbrecht, & Kingstone, 2008).

To date, only one study recorded ERP responses when the two dots depicted the feet of PLD human walker were presented as a cue (Wang, Yang, Shi, & Jiang, 2014).

Whereas other cueing studies (Schuller and Rossion 2001; Tipper et al., 2008) recorded ERPs target locked responses in Wang and colleague' study (2014), the authors recorded cue-locked ERPs components demonstrating that encoding of spatial information provided by PLDs of biological feet motion induce an attentional orienting as already demonstrated by employing other social stimuli such as eye gaze. Specifically, results revealed that participants orient their attention towards the walking direction of feet motion sequences, which triggers an early directing attention negativity (EDAN) in the occipito-parietal region 100–160 ms after the stimulus onset.

Taken together, this behavioral and electroencephalographic evidence reveals that the walking direction of biological vertebrates can guide automatic shifts of attention in adult observers as was previously demonstrated for eye gaze. In this respect, an intriguing question concern the developmental origin of biological motion perception and the origin of the ability to use directional information of biological motion to guide attention.

3.5 Detecting motion from complex arrays in the first year of life.

From a developmental perspective, behavioral studies showed that 3-day-old newborns have a spontaneous preference for biological motion rather other types of motion, such as random motion and mechanical motion (Bardi et al., 2011; Bidet-Ildei et al., 2014; Simion et al., 2008). Using the preferential looking paradigm, these authors tested newborns spontaneous preference for biological motion depicted in complex arrays. The study by Simion and collaborators (2008) demonstrated that when newborns were presented with a PLD of a walking hen compared to a PLD where dots move in a random fashion, newborns preferred biomechanical motion kinematics pattern rather than the random one. In same vein, newborns preferred biomechanical motion rather than a mechanical movement defined as linear movement of each single dots along the vertical axis (Bardi et al., 2011). This evidence, taken together, seems support the hypothesis done by Troje and Johnson (Troje & Westhoff, 2006; Johnons, 2006), that since birth the sensitivity towards biological motion is only driven by the local information of biological motion.

Subsequently works, suggest that the sensitivity towards global level of information of biological motion, such as that the array of dots is organized as a body, emerges later during development.

The first study that tested infants' sensitivity for biological motion by using complex arrays of dots was done by Fox and McDaniel (1982). The authors tested 4- and 6-month-old infants' visual preference for a biological motion compared to an array of elements moving in a random fashion and they used PLDs representing a walking human figure. Infants were presented to a PLD depicting a figure of a human walking they preferred biological motion both at 4 months of age and at 6 months of age. In a series of studies, Berthental and colleagues investigated infants' ability to organize complex arrays of dots as a coherent figure. At 5 months of age, infants are able to discriminate PLD walker from the same stimulus with scramble spatial relationship (Berthental, Proffitt, & Cutting, 1984) or with perturbed local rigidity between joints (Berthental, Proffitt, & Kramer, 1987) suggesting the emergence of sensitivity toward global information level of biological motion. This evidence, supports the hypothesis done by Troje and colleagues that the second mechanism that would be responsible to recognize and identifying agents based on configural information, would not be innate but an experience-dependent mechanism that become functioning during the development. Moreover, the extraction of relevant social information would be supported by this mechanism (Chang & Troje 2009), and this information might be used to interpret other intentions and depositions and moreover they might be used for specific tasks such as orienting attention.

In light of this, a study done by Kuhlmeier and colleagues (2010) demonstrated that at 6 months of age, infants are sensitive to PLDs orientation and they are able to extract information of directionality from PLDs depicting human figure. Testing 6-month-old infants with a habituation paradigm the authors demonstrated that infants are able to extract information of directionality only when the PLDs is presented upright and most intriguing when no actual translation is occurring.

To summarize, in agreement with Troje, and according to Moore’s taxonomy (2012), perception of biological motion seems to develop gradually during the development; it starts from an initial sensitivity toward local cues of biomechanical motion and the sensitivity towards global level of information emerges around 5-6 months of age for human motion. Moreover, at 6 months of age, when PLDs were presented upright infants are able to extract directionality information from human motion (Khulmeier, Troje, & Lee, 2010).

An intriguing question that is still open, is that of discovering at which age level during infancy walking direction can trigger a visuo-spatial orienting of attention as it happens in adults.

3.6 Biological motion and orienting of attention in infancy

3.6.1 Behavioral and electrophysiological evidence

Orienting of attention is a crucial mechanism that is functional since birth. It is supported by subcortical structures (i.e. the superior colliculus) (Simion et al., 1995), and it allows newborns to process potentially relevant information in the surrounding space.

Research has started to be carried out in an attempt to investigate whether information of directionality conveyed by biological motion, may trigger visual-spatial orienting in a way similar to what other directional social cues do in infancy (i.e., eye-gaze, pointing and grasping gestures) (Bardi et al., 2015).

Behavioral studies, demonstrated that social cues, as for example hand gesture, can trigger an orienting of attention also in infancy. Daum and Gredebäck (2011), tested infants of 3, 5 and 7 months of age employing a cueing paradigm with a static human hand (i.e. grasping action) or mechanical claw as cue. Findings demonstrated that infants have a cueing effect only from 5 months of age and only with the human hand. Specifically, infants showed faster saccade latencies for congruent rather than incongruent targets only when they were cued by human gesture. Authors suggest that the emergence of cueing effect from 5 months of age, might be consequence of the experience that infants from 5 months age have with their own hand gesture. Moreover, the absence of the cueing effect in younger infants might be due to the absence of a perceived translational movement. As shown in a previous study (Farroni, Johnson, Brockbank, & Simion 2000), the presence of movements seems to be necessary to elicit orienting of attention, as well as the cueing effect, in younger infants. Specifically, Farroni and colleagues (2000) tested 4-month-old infants with a cueing paradigm employing gaze as a cue. Results showed that infants have faster responses for congruent target rather than incongruent only when the movement of the eyes was perceived. In contrast, when the motion of the pupils was hidden by a blinking face, infants did not show any facilitation in orienting their attention.

The first answer to the question of whether information of directionality conveyed by biological motion can trigger and orient visuo-spatial attention also in infants was done by my previous work (Bardi et al., 2015). In this study, we demonstrated that 6-month-old infants use the information of directionality conveyed by human motion to orient their attention towards the spatial hemifield indicated by PLDs of a human walker. Starting from the behavioral evidence that infants are able to extract directionality from PLDs of human walker (Kuhlmeier et al., 2010), we tested infants with a cueing paradigm employing a central PLD of human motion walking on a treadmill followed by a peripheral target. This PLD cue stimulus could be presented upright or upside-down and it was facing either right or left. As for adults (see previous section), infants' saccadic reaction times were faster in response to targets appearing at congruent rather than incongruent spatial positions when the cue was presented upright but not when it was presented upside-down. Therefore, this study demonstrated that the walking direction of a human motion PLD can trigger automatic visual-spatial orienting in 6-month-old infants and participants have faster saccadic reaction times when the target is presented at the spatial position cued by a PLD of a human walker. In light of this behavioral evidence, it seems that kinematic information of human motion, as well as motion performed by other stimuli that vehicle social information, is able, by itself, to trigger orienting of attention.

Moreover, a series of studies (i.e. Gredebäck, Melinder & Daum, 2010; Senju, Johnson & Csibra, 2006; Richards, 2000; Xie & Richards 2017) have also used non-invasive techniques (EEG/ERP) to investigate whether possible attention-related sensory gain effect to targets appearing at cued relative to uncued associated with this attentional priming effect occurring early in life. Richards (2000) demonstrated that infants are able to shift their attention towards the location indicated by an exogenous cue and the effect is indexed by specific ERP responses. Richard's study revealed that infants oriented their attention overtly (i.e. gazing) towards the spatial position indicated by peripheral exogenous cues (i.e. flashes of light), showing shorter saccade latencies for congruent rather than incongruent trials. Moreover, infants exhibited distinct ERP (e.g., P1, N1) responses to spatially cued stimuli compared to non-cued stimuli (Richards 2000, 2005). Specifically, the P1 component was found to be larger for congruent than incongruent trials across occipital electrodes in 4.5- and 6-month-old infants but no difference was found in 3-month-olds. Similar results were found for the N1 component, which is the negative deflection following P1 (Richards 2000, 2005). The modulation of these sensory components (e.g. P1, N1) reveals that infants orient their covert attention before their overt attention, thus showing that attention-related sensory gain effect to targets that appeared at cued relative to uncued spatial position is present at very early stages of development.

Different results came from studies that used central endogenous cues. Several studies used social stimuli (i.e. faces, eye gaze pointing, hand gesture) in modified versions of the traditional cueing paradigm and, recording the EEG signal, the modulation of the ERP components varied as function of the variation of the paradigm and the nature of the stimulus used. A first result, using a cueing paradigm in which the initial presentation of the target stimulus in one of two possible spatial locations was followed by presentation of the cue (a pointing hand) with 6-month-old infants, showed that the temporo-parietal component P400 is sensitive to cue-target congruency relations, being higher in amplitude for incongruent relative to congruent conditions (Bakker, Daum, Handl & Gredebäck, 2014; Gredebäck et al., 2010). A second version of the cueing paradigm requires the initial presentation of a neutral, non-directional cue (a face looking neither right or left) followed by a target appearing either at a left or right spatial location. Disappearance of target stimulus is synchronously coupled with appearance of a directional cue (a face looking right or left). Studies carried out with this paradigm have revealed that the temporo-parietal component N290 is sensitive to congruency relations starting from 9 months of age (Senju et al., 2006). Similar results were found in 6-month-old infants, using a cueing paradigm where the target presentation was preceded by a possible or impossible hand gesture (Natale et al., 2017). Natale and colleagues found that the N290 component is modulated by the congruency relation between cue and target but only when the cue is a possible hand gesture. Taken together, the available evidence demonstrates that, starting from the first months of life, the infant brain can differentiate congruency from incongruency relations. In addition, these results seem to indicate that a functional advantage may be achieved by detection of social or non-social cues, which could facilitate processing of potentially relevant information. Of note, all these ERP studies made use of static images of social stimuli.

An issue that still needs to be explored relates to the kinematics proprieties of motion that are crucial in triggering orienting of attention and the neural mechanisms underpinning this cueing effect elicited by biological motion. As suggested by behavioral evidences, motion seems to a have a central role to elicit orienting of attention in infancy (Farroni et al., 2000; Daum & Gredebäck, 2011; Bardi et al., 2015) Importantly, human motion is characterized by specific kinematic properties and all human actions (i.e. eye gaze, hand gesture, and walking) obey to specific rules resulting from the physical constraints of the human body (Moore, 2012). As demonstrated by Bardi and colleagues (2015) 6-month-old infants orienting of attention when PLDs human walker were used as cue. However, Bardi and colleagues (2015) recorded only overt responses, such as saccade latencies. Thus, this study does not clearly demonstrate that the human motion induces an orienting of attention in the absence of eye movements.

Even though, according to Rizzolatti and colleagues' (1987) premotor theory of attention, the process of preparing the eyes to move is the mechanism by which endogenous spatial attention is engaged at target location before active stimulation, regardless of the nature, overt or covert, of the attentional shift, Bardi and colleagues' results might be argued to be valid only for overt shifts of attention. In particular, they did not demonstrate the existence of sensory gain effects in response to targets appearing at cued relative to uncued locations when the cue is represented by biological motion walking direction. In order to answer this question, an EEG study is required. If human motion really triggers covert orienting of attention, by analyzing the ERPs, one should observe a specific modulation of the sensory components (P1 and N1) occurring before eye movements.

Considering this evidence, the aim of the experiments described in the present chapter, was to investigate the neural correlates of the attentional effect accompanying mechanisms of visual-spatial orienting triggered by upright biological motion walking direction.

According to Troje's model (2006), that states that the subcortical system that is deputed to detection of directionality information is present since birth, it might be plausible to hypothesizes that even at 3 months of age infants can extract this information and use it to orient attention towards the peripheral space. However, to date no evidence is present in literature with infants younger than 6 months of age. For this reason, in the following experiments infants of 3 and 6 months of age were tested to describe a developmental trajectory of how our visual system use kinematic information conveyed by biological motion to orient attention in surrounding space. To this end, the cueing paradigm used by Bardi and colleagues (2015) was adopted and coupled with the recording of EEG signal. As in the previous behavioral and EEG infants' studies (i.e. Bardi et al., 2015; Farroni et al., 2000; Natale et al., 2017), in the following experiments only congruent and incongruent trials were presented. In the absence of neutral trials, facilitatory and inhibitory effects are confounded. Accordingly, the aim was to investigate the neural correlate of these attentional effect, regardless of whether they originate by the facilitation of cued trials, the inhibition of uncued trials or both.

Experiment 7: 3month-old infants

The aim of Experiment 7 is to test 3-month-old infants' ability to extract walking direction from PLDs of human walker and to orient visuo-spatial attention toward the spatial position indicated by walking direction. Infants were tested with a cueing paradigm (Bardi et al., 2015; Natale et al., 2017), where a PLDs of human walker presented upright was employed as cue. The cue, could walk either toward the left or right direction, and was followed by a peripheral target that might appear in a congruent or incongruent spatial position with respect to the walking direction of the cue. Saccadic latencies were recorded coupled with ERP target locked to test: 1) the possibility that walking direction can trigger orienting of attention in 3-month-old infants; 2) the possible effect on sensory components (i.e. P1), of the orienting of attention triggered by walking information.

Methods

Participants

Eighteen healthy, full-term 3-month-old infants (10 females, mean age= 3 months and 20 days, range= 90-140 days) participated in the study. One participant was discarded because starting crying during testing. For this reason, seventeen out of 18 participants were considered for behavioral analysis. Eleven out of the 17 infants (7 females), were considered for ERP target-locked analysis. The criterion adopted for the inclusion in the sample of the ERP analysis was: at least 10 trials in one of the two experimental condition (congruent vs. incongruent). The average of trials presented for both conditions were 11 for the congruent and 12 for the incongruent. Infants were tested if awake and in an alert state, and after parents gave their informed consent. The experimental protocol was approved by the Ethical Committee of the University of Padova (protocol number 1956).

Stimuli

Cue stimuli consisted of frame sequences of a walking human figure. The human walker, computed as the average walker from motion-captured data of 50 males and 50 females (Troje, 2002, 2008), was depicted by a set of 11 markers representing the main joints and the head of the person. The translating component of the walk was removed such that the human displayed stationary walking. All walkers were presented in profile, either facing leftward or rightward, and were shown with a gait frequency of 0.76 Hz. All stimuli appeared as white dots on a black background and the full point light figure subtended a visual angle of 7.59°x 3.81°. The target stimulus consisted of a colorful ball and it subtended a visual angle of 1.43°x1.43° and the distance between the center of the cue and the center of the target was 12.68° (13.5 cm). At the beginning of each trial, to attract infants’ attention to the center of a screen, a series of silent animated video (e.g. cartoons) was presented as attention getter. The attention getter lasted until the eye of the infants was aligned with the center of the screen.

Apparatus and Procedure

Testing took place in a dimly illuminated room. Infants were seated on a parent’s lap approximately 60 cm from screen (24 inches; resolution 1024 x 768 pixels) used for stimulus presentation. A two-machine solution was adopted for experimental control. The sequence and timing of stimulus presentation was controlled using a computer with E-Prime 2.0. This computer was interfaced with Net Station (Electrical Geodesic, Eugene, OR.) via a serial connection. Net Station was used to record the critical sequence of events along with the high-density EEG data. Infants’ eye blinks and saccades were monitored online by an experimenter via a visual inspection of the continuous EEG signal recorded. Additionally, a video camera situated above the screen used for stimulus presentation recorded the infants’ face and gaze behavior.

A cueing paradigm was employed (Natale et al., 2017; Posner, 1980). As shown in Figure 1, each trial began with a visually animated but silent fixation point, (*attention getter)* randomly selected among 16 different animations, displayed at the center of the screen). As soon as the infant looked at it, this attention getter was replaced by the visual-spatial cue, namely a PLD of a human body walking toward the right or the left position. The cue was shown for 1200 ms and, after a variable delay (range: 300-500 ms), the target stimulus was displayed for 200 ms at a peripheral spatial location (~10 degrees of visual angle from the center of the screen) either congruent or incongruent with the cue walking direction (Figure 3.3).

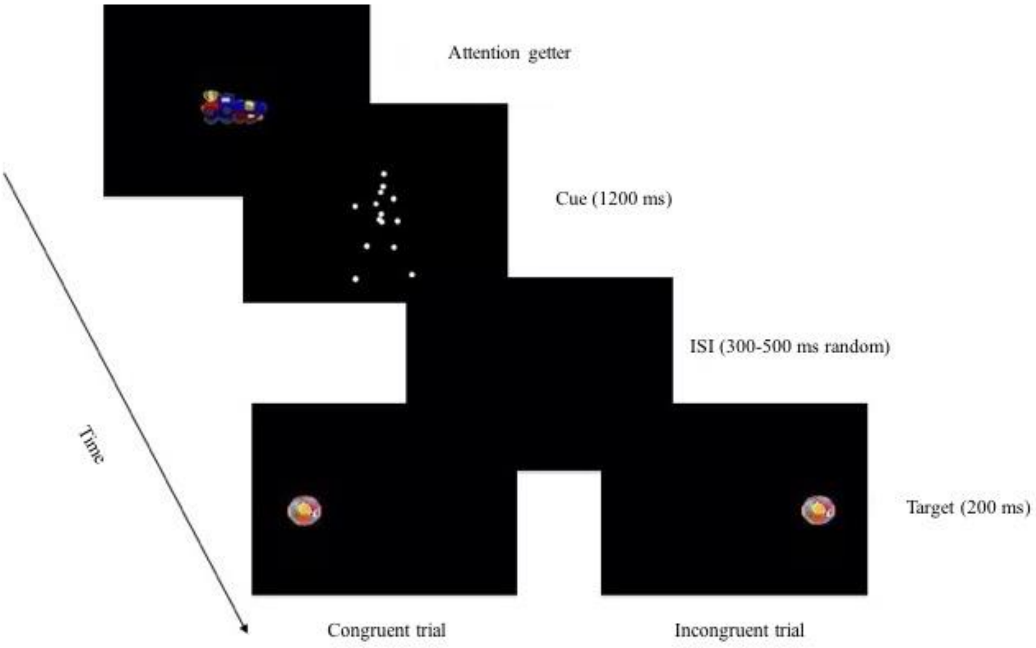

Figure 3.3 Representation of the sequence of events in the cueing paradigm. Two types of trials were presented: Congruent and Incongruent trials. In congruent trials the target appeared in the spatial position cued by biological motion walking direction; in incongruent trials the target appeared in the spatial position not cued by biological motion walking direction.

Stimuli were presented in blocks of 16 trials, eight congruent (four with left-and four with right-sided targets) and eight incongruent (four with left-and four with right-sided targets). The animated fixation point varied on each trial. Also the target stimulus varied, being randomly selected among four possible types. In order to obtain as many trials as possible from each infant, there was no restriction in number of blocks or trials shown: they were played as long as the infant was not fussy. Specifically, the experimental session was terminated when infants looked away from the screen during five consecutive trials. On average, 35 trials, were presented to each infant, with no difference between number of valid (N=20) and invalid (N=23) trials, *t*(10)= , *p*=.09.

Gaze behavior recording and coding

Infants' gaze behavior was scored with a computerized frame-by-frame observational coding system (40 ms resolution), enabling two independent coders to identify the exact time at which the infant's pupil began moving horizontally, indicating gaze shift in the direction of the cue and toward/away from the target stimulus. Specifically, gaze shifts toward the target were coded to identify correct gaze behavior and to calculate the Saccadic Reaction Time (SRT: the elapsed time between the onset of the target and the onset of the infant's gaze shift). To calculate inter-coders reliability, the second observer coded gaze behavior in a sample of eight participants. Pearson correlation revealed a high degree of agreement between the two coders, $r = 0.99$, $p < .0001$.

EEG recording and analysis

Continuous scalp EEG was recorded from a 128-channel HydroCel Geodesic Sensor Net (Electrical Geodesic, Eugene, OR) that was connected to a NetAmps 300 amplifier (Electrical Geodesic, Eugene, OR) and referenced on-line to a single vertex electrode (Cz). Electrical signal was recorded from 124 of the 128 channels on the nets as 4 electro-oculographic channels (that are typically positioned on the face) were removed to enhance infants' tolerability of the net. Channel impedance was kept at or below 100 KΩ and signals were sampled at 500 Hz. EEG data were pre-processed off-line using EEGLAB (Delorme & Makeig, 2004). As a first step, data segments were filtered using a 0.3–30 Hz band-pass filter and re-referenced to average reference. The EEG signal was segmented to 350 ms post-stimulus onset, with a baseline period beginning 100 ms prior to target onset and baseline corrected using mean voltage during the 100 ms pre-stimulus period. Automated artifact detection was applied to the segmented data to detect individual epoched that showed >200μV voltage changes within the segment period. Bad segments were marked when belonging to trials in which fast eye movements occurred, as assessed by off-line coding. Segments in which correct gaze shifts occurred were marked as bad if gaze shift started before the target off-set. Thus, segments with SRTs faster than 200 ms were marked as bad. Finally, we also marked as bad segments belonging to trials in which distractions occurred. Bad segments identified by either procedure were excluded from further analysis. A linear interpolation was conducted to correct for any rejected channels using the five closest electrodes.

Since the design of paradigm (i.e. spatial visual cueing with peripheral target) require to infants to shift their eyes; saccades occurred during the task. To remove the effect of eye movements, an Independent Component Analysis (ICA) was done using the “extended runica” function in MATLAB. The analysis was performed on the EEG segmented data for each single participant. The 124 components were plotted based on the decreasing variance explained. All the components were visually inspected and were rejected those which have eye movement according to the 2D topographical plots. Specifically, those components that have a positive/negative distribution that suggest a frontal dipole, i.e. eye movement, and those components that have frontal and posterior opposite polarity, i.e. eye blink, were excluded.

For each participant, average waveforms were generated within each experimental condition (congruent and incongruent) only if at least 7 artifact-free trials collapsed across target side were overall available per condition.

Results

Saccadic Reaction Times (SRTs)

All Infants were considered for statistical analysis of behavioral data. On average, percentage of correct (i.e. saccade toward spatial side where target appeared) gaze shifts was 75% with no difference between congruent (39%) and incongruent (40%) trials; 20% of detected gaze shifts were identified as distractions (infants didn't look at the monitor); finally, there were a few spatial errors (saccade toward the spatial position where the target didn't appear) and anticipations/delays (saccade stared before target appearing), i.e. overall 5%. Consequently, a paired T-test between mean SRTs in congruent trials and mean SRTs in incongruent trials was carried out. Infants' SRTs were not faster in response to congruent trials (M=376 ms, SD=87) relative to incongruent trials (M=394 ms, SD=101), t(16)=-1.252, *p*=.228 (Figure 3.4).

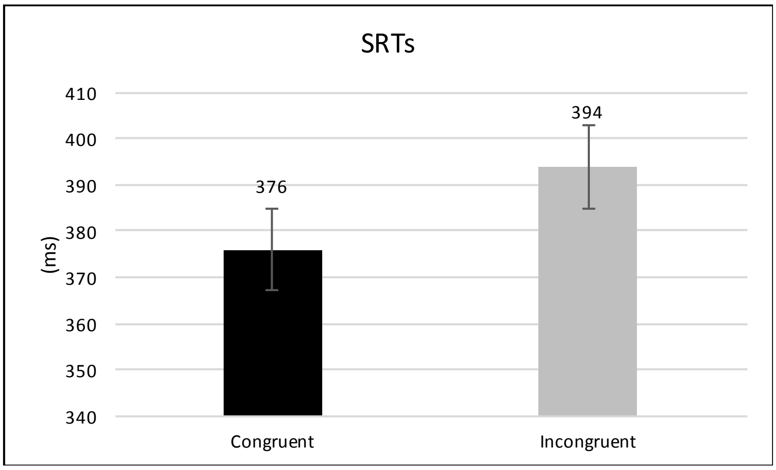

Figure 3.4 Average of saccadic reaction time of Experiment 7

Target-locked P1 ERP component

Inspection of the grand-averaged waveforms revealed that the P1 ERP component was reliably elicited at target onset over occipito-parietal scalp sites. Based on visual inspection of both the grand-averaged and individual waveforms, 17 clusters of electrodes were created for the ERP target-locked analysis. According to 10-10 system of electrodes, clusters for O1, OZ, O2, I1, IZ, I2, PO7, PO8, PO9, PO10, P7, P8, P9, P10, TP7, TP8, CZ were created using the average of the three closest electrodes (Table 1). Based on grand-averaged data and individual data, peak and mean amplitude of P1 were extracted within a time window of 100 to 150 ms.

Clusters of Electrodes	*Electrodes Number HGSN system*
O1	*66 70 71*
OZ	*71 75 76*
O2	*76 83 84*
I1	*69 73 74*
IZ	*74 81 82*
I2	*82 88 89*
PO7	*59 65 66*
PO8	*84 90 91*
PO9	*64 65 68*
PO10	*90 94 95*
P7	*51 58 59*
P8	*91 96 97*
P9	*57 63 64*
P10	*95 99 100*
TP7	*46 50 51*
TP8	*97 101 102*
CZ	*7 31 55 80 106*

Table 1. On the left column, Cluster of electrodes created for ERP analysis in accordance with 10-10 system. On the right column, electrodes numbers selected from HGSN system to create clusters

Figure 3.5 shows the overall ERP responses in occipital, parietal and parietal-occipital cluster.

A repeated measure ANOVA on the peak amplitude with Congruency (Congruent vs. Incongruent) and Electrodes as within subject factors was performed. This analysis did not reveal any significant main effect or interactions.

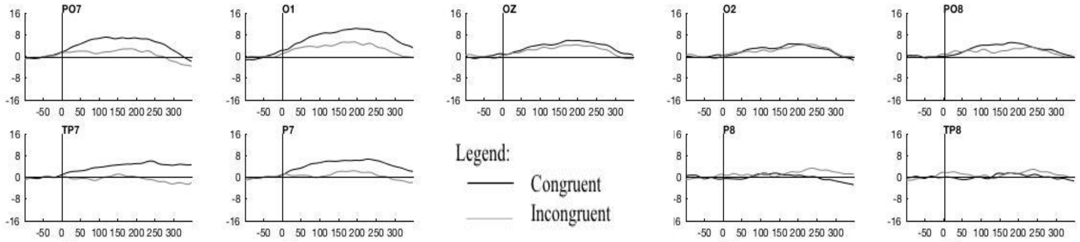

Figure 3.5 Grand Average plot in occipital and parietal clusters: response to congruent condition is represented in black, whereas response to incongruent condition is represented in grey

Overall, results of Experiment 7 seem to suggest that at 3 months of life, infants are not able to extract information of directionality from a PLDs depicting a human walker. The absence of behavioral and neural effects it might due to the fact that the at 3 months of age, infants have not yet sufficient experience with other motion to extract information of directionality.

Experiment 8: 6-month-old infants

The aim of Experiment 8 is to test 6-month-old infants' ability to extract walking direction from PLDs of human walker. Infants underwent the same paradigm and the same condition employed in Experiment 7.

Saccadic latencies were recorded coupled with ERP target locked to test: 1) the possibility that walking direction can trigger orienting of attention in 6-month-old infants; 2) the possible effect on sensory components (i.e. P1), of the orienting of attention triggered by walking information.

From a behavioral perspective, we predicted to observe a modulation of infants' oculomotor behavior as a function of congruency/incongruency relations between the walking direction of the upright walker and the appearance of a peripheral target stimulus. From a neural point of view, if human motion orients visuo-spatial attention, we predicted to observe a modulation of the sensory ERP components (i.e. P1 and N1). Accordingly, we hypothesized these early ERP components to exhibit higher amplitude in response to targets appearing at congruent relative to incongruent spatial locations.

In addition, I predicted that the modulation of sensory components should originate from brain areas involved in visual processing. Therefore, besides analyzing the ERP component, I applied cortical source analysis to examine the brain regions that might generate the recorded ERPs involved in infants orienting of attention (Richards, 2005, Xie & Richards 2017). These studies have suggested the cortical regions generating the P1 validity effect could be located in contralateral Brodmann'areas 18 and 19 (Richards 2005) and in the contralateral ventral temporal areas (Xie & Richards 2017). Cortical sources for N1 validity effect were instead localized in BAs 7, 18, 19 (Richards 2005), the contralateral inferior and middle occipital regions and middle and superior temporal regions (Xie & Richards 2017).

Methods

Participants

Twenty-four healthy, full-term 6-month-old infants (10 females, mean age=6 months and 7 days, range=183-224 days) participated in the study. All of them were considered for behavioral analysis. Eleven out of the 24 infants (7 females, mean age=6 months and 7 days, range=183-205 days) were considered for ERP target-locked analysis. The criterion adopted for the inclusion in the sample of the ERP analysis was:

at least 10 trials in one of the two experimental condition (congruent vs. incongruent). The average of trials presented for both conditions were 11 for the congruent and 12 for the incongruent. Five additional infants were tested, but not included in the final sample of participants because of fussiness or excessive movement artifacts, resulting in no reliable performance. Infants were tested if awake and in an alert state, and after parents gave their informed consent. The experimental protocol was approved by the Ethical Committee of the University of Padova (protocol number 1956).

Stimuli

Stimuli were the same employed in Experiment 7.

Apparatus and Procedure

Apparatus and procedure were the same employed in Experiment 7.

Gaze behavior recording and coding

Gaze behavior was recorded and coded with the same setting of Experiment 7. The agreement between coders was $r = 0.99$, $p < .0001$.

EEG recording and analysis

EEG system was the same used in Experiment 7 and the ERP analysis was conducted following the same pipeline of Experiment 7.

Cortical Source Localization

The Cortical Source analysis was performed using Fieldtrip toolbox (Oostenveld, Fries, Maris, Schoffelen, 2011) and in-house custom MATLAB scripts. The analysis was performed following four major steps: 1) selection of anatomical MRIs; 2) construction of realistic head models: 3) definition of regions of interests

(ROIs); 4) source reconstruction (i.e., current density reconstruction; CDR) (for details, see Xie and Richards, 2017).

The selection of the MRI was done from the Neurodevelopment MRI Database (Richards and Xie, 2015) by selecting the MRI average template for 6-month-old participants. The infant MRIs were segmented into: scalp, skull, cerebral spinal fluid, white matter, gray matter, nasal cavity and eyes (Richards, 2013).

Twenty-three brain regions were chosen for ROI analysis based on past identification of dipoles responsible for generating scalp measurements (e.g., P1) in infant studies (i.e. Xie & Richards, 2017). These ROIs included the separate left and right volumes for the anterior fusiform gyrus, middle fusiform gyrus, medial inferior occipital lobe, lateral inferior occipital lobe, middle occipital lobe, superior occipital, parahippocampal gyrus, posterior inferior temporal gyrus, posterior middle-superior temporal gyri, and temporal pole (20 ROIs). A single bilateral ROI was used for the lingual gyrus, central occipital lobe, and parietal lobe (3 ROIs).

The ERP data surrounding the P1 peaks was used to estimate the current density amplitudes (i.e., CDR values) for every location in the source volume model. The CDR values were then summed over each source location in a ROI and divided by the total volume of the ROI. For statistical analysis, the CDR value was averaged with the time window (±10 ms) around the P1 peak.

Results

Saccadic Reaction Times (SRTs)

Infants included in the ERP target-locked analysis (N=11) were considered for statistical analysis of behavioral data. On average, percentage of correct (i.e. saccade toward spatial side where target appeared) gaze shifts was 70% (range = 60-80) with no difference between congruent (39%) and incongruent (40%) trials, *t*(10)=-1.5, *p*=.19; 18% of detected gaze shifts were identified as distractions (infants didn't look at the monitor); finally, there were a few spatial errors (saccade toward the spatial position where the target didn't appear) and anticipations/delays (saccade stared before target appearing), i.e. overall 3.2%. Consequently, a paired T-test between mean SRTs in congruent trials and mean SRTs in incongruent trials was carried out. Infants' SRTs were faster in response to congruent trials (M=285.7 ms, SD=23.5) relative to incongruent trials (M=313.9 ms, SD=32.2), t(10)=2.48, *p*=.004. Analogous investigation was carried out for the entire sample of infants tested (N=24). On average, percentage of correct gaze shifts was 75.4% (range=54-90%), with no difference between congruent (36.7%) and incongruent (38.7%) trials, *t*(21) =-1.5, *p* =.13. 21% of detected gaze shifts were identified as distractions; 3.2% were identified as spatial errors. A paired T-test was carried out between mean SRTs in congruent and incongruent trials. Infants were faster to orient their gaze in congruent trials (M=281 ms, SD=24,5) rather than in incongruent trials (M=317ms, SD=30,4), t(21)= -3.482 *p*=.002 (Figure 3.6).

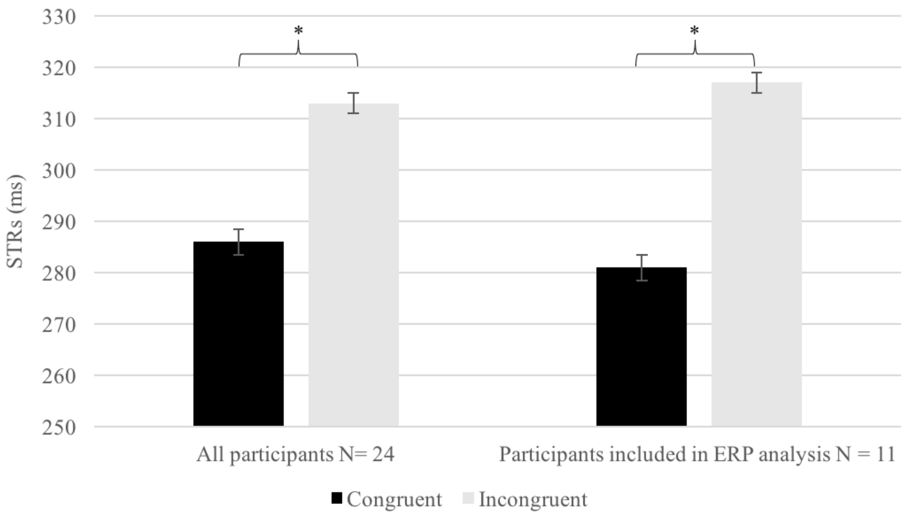

Figure 3.6 Saccadic reaction times. On the left behavioral data from all participants tested; on the right behavioral data for the sub-sample included in ERPs analysis. * *p* <.05

Target-locked P1 ERP component

Inspection of the grand-averaged waveforms revealed that the P1 ERP component was reliably elicited at target onset over occipito-parietal scalp sites. Based on visual inspection of both the grand-averaged and individual waveforms, 17 clusters of electrodes were created for the ERP target-locked analysis. According to 10-10 system of electrodes, clusters for O1, OZ, O2, I1, IZ, I2, PO7, PO8, PO9, PO10, P7, P8, P9, P10, TP7, TP8, CZ were created using the average of the three closest electrodes (Table 1). Based on grand-averaged data and individual data, peak and mean amplitude of P1 were extracted within a time window of 100 to 150 ms.

Figure 3.6 shows the overall ERP responses in occipital, parietal and parietal-occipital cluster. Peak of P1 component approximately occurs after 100-150 ms of target onset. P1 component was larger for congruent condition in the contralateral clusters.

Figure 3.7 shows the topographical activation on the scalp in both condition. In both condition, is present a distribution (positive in the back and negative in the frontal areas) at P1 component that might suggest the presence of a source dipole that generates this ERPs component. However, starting from 50 ms after target onset the activation is greater in the congruent than in incongruent condition.

A repeated measure ANOVA on the peak amplitude with Congruency (Congruent vs. Incongruent) and Electrodes as within subject factors was performed. This analysis revealed a main effect of Congruency, *F(1,10)*= 4.63, *p*=.057, η^2_p=.31. Overall the amplitude of P1 component, was larger for congruent (4.94 µV) than incongruent trials (3.46 µV).

Consequently, a paired T-test was separately carried out on peak and mean amplitude, for each cluster, between congruent and incongruent trials. The analyses revealed a significant effect as a function of congruency in PO10 and P10 clusters. Specifically, P1 component, was larger for congruent (6.39 µV) than incongruent trials (1.93 µV) in PO10, *t*(10)=.3.303 *p*=.008 and in P10 *t*(10)= 2.707, *p*=.022 (congruent trials = 3.48 µV, incongruent trials = - 0.86 µV). No significant effects were found on the mean amplitude.

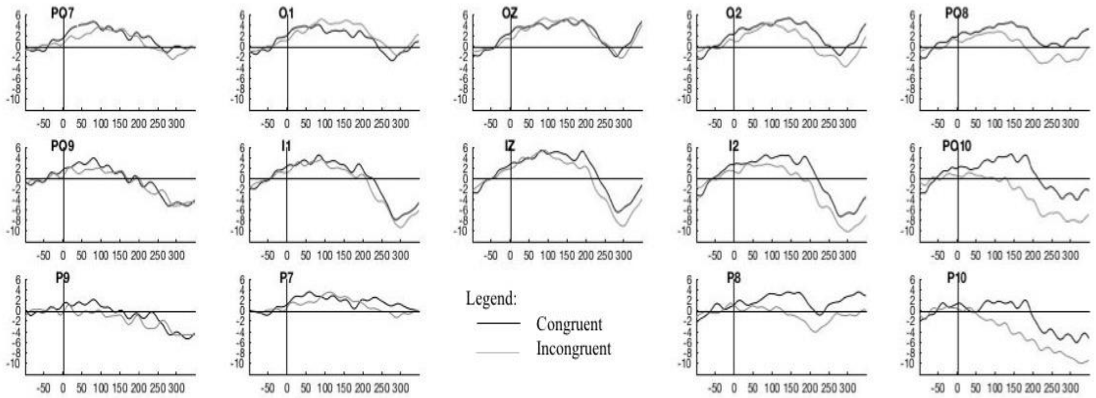

Figure 3.6 Grand Average plot in occipital and parietal clusters: response to congruent condition is represented in black, whereas response to incongruent condition is represented in grey

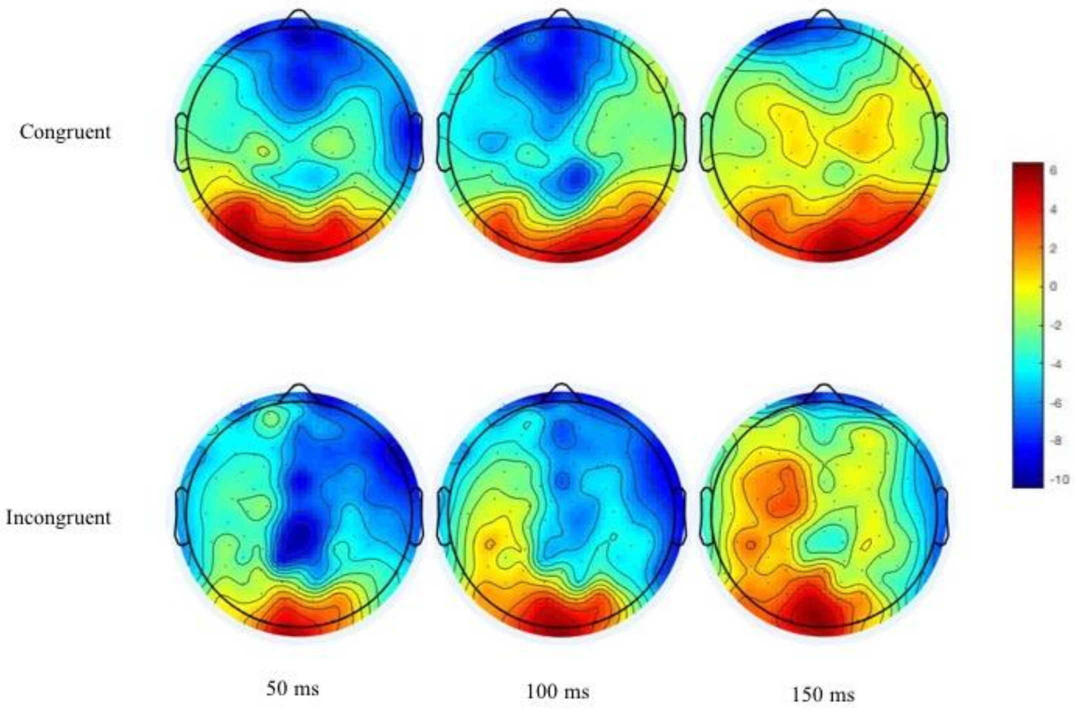

Figure 3.7 Grand Average topoplot. Time labels indicate milliseconds after target stimulus onset. Response to congruent condition is represented in the upper part, whereas response to incongruent condition is represented in the lower part

Cortical Analysis

Cortical source analysis focused on the mean current density reconstruction amplitude (CDR value) in the ROIs that are potential cortical sources of the P1. The first step of the analysis pipeline was conducted to determine the effect of cue-target congruency on CDR value around the P1 ERP peak latency (140 ms) in the ROIs. The ERP analysis showed a P1 validity effect in the PO10 and P10 clusters. The CDR values were therefore tested as a ‘‘congruency effect’’ with congruent versus incongruent trials for each ROI segment. Two different ROIs had a significant congruency effect: parahippocampal gyrus and the anterior fusiform gyrus. Both this

ROIs are contralateral to the target position. This result, found in the aforementioned areas might reflect the facilitation in processing visual information when are cued by a previous stimulus. However, no congruency effect was found in the inferior occipital lobe and in lateral and medial occipital lobe. Figure 3.8 shows the CDR values during the time period surrounding the P1 peak (+48 ms/ -48ms) for valid and invalid condition in the two ROI that showed a significant effect. The congruent condition had larger CDR values (dotted blue line) starting from 16 ms before the P1 peak. Approximately around 30 ms after the P1 peak, the difference between two conditions is greater. Figure 3.9 shows the bar graph of the CDR values for the two conditions in the two ROI that showed a significant effect. Average CDR values is greater in congruent than in incongruent condition. More specifically, the error bars (i.e. the standard errors of the means) did not overlap, suggesting a significant difference between condition.

Figure 3.10 shows the brain areas involved as cortical sources of the P1 component. The 2D images depicted in panel a), b), c); show the difference between congruent and incongruent condition. Figure 7, panel d) is 3D plot that depicted the difference between congruent and incongruent conditions in the brain areas that show a significant effect and are mainly involved to originate the P1 ERP component.

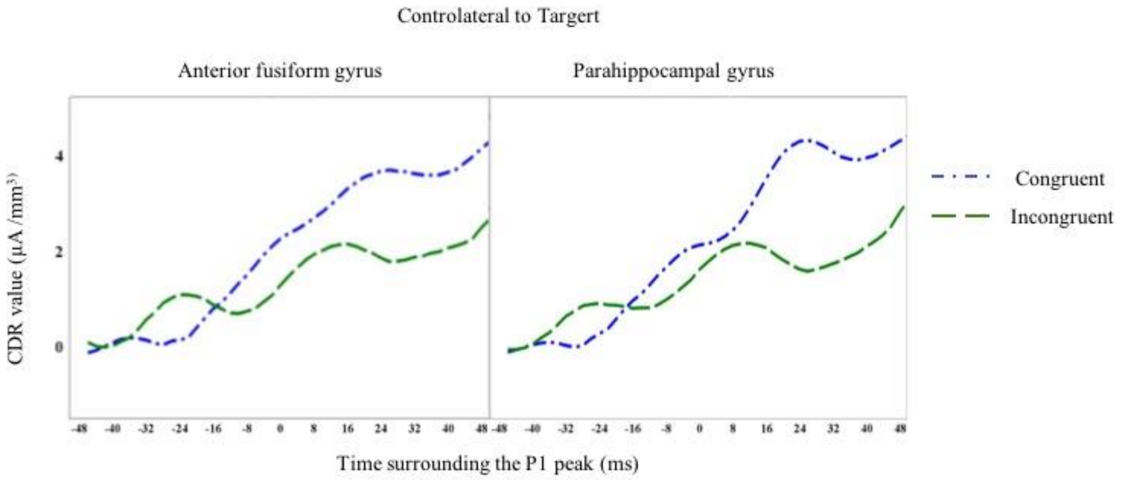

Figure 3.8 Line figures of CDR value from -48 ms to 48 ms around the P1 peak latency. Anterior fusiform gyrus and parahippocampal gyrus are the two ROIs that show significant congruency effect. Both thiese areas are contralateral to target position.

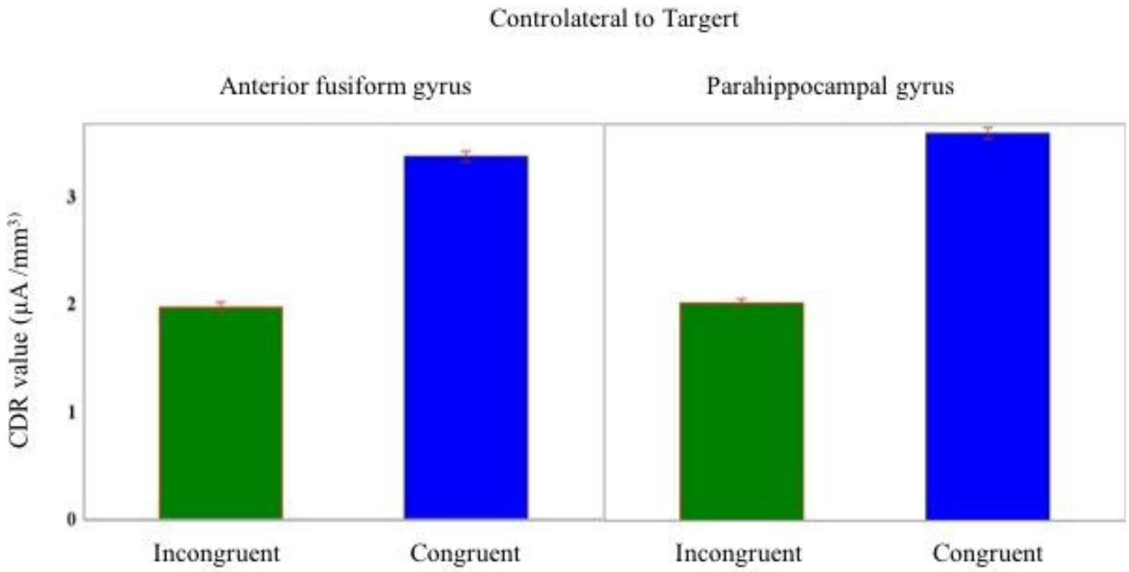

Figure 3.9 Bar graph of the CDR value in the two areas that show a congruency effect.

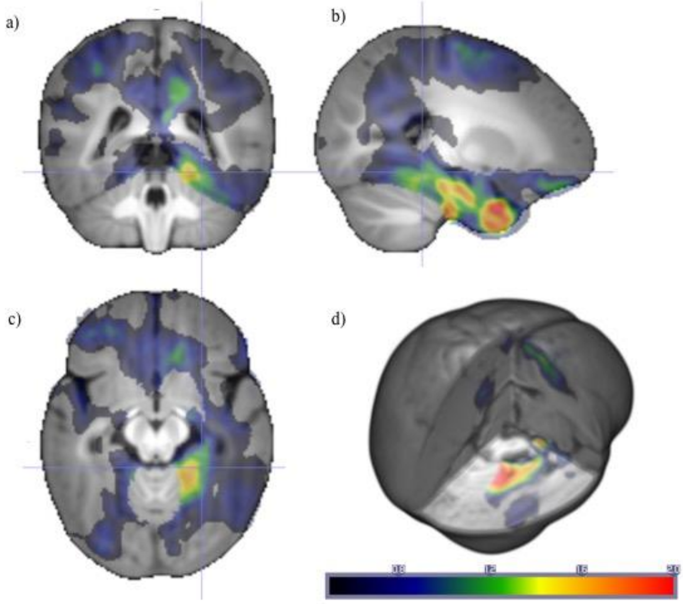

Figure 3.10 2D and 3D maps of the Congruency effect (i.e. activation for congruent condition – activation for the incongruent condition) surrounding the P1 peak in brain source. Panel a, b, c, are 2D coronal, sagittal and axial plots. Panel d), is the 3D plot of the brain areas mainly involved to originate P1 congruency effect. All these data are plotted in an average 6-months-old brain template.

Overall, results of Experiment 8 suggest that 6-month-old infants are able to extract walking direction from o PLD stimulus. Specifically, they showed faster saccadic reaction time for congruent rather than incongruent trials. ERPs evidence, demonstrate that the attentional effect occurs in the initial stages of visual processing. Specifically, target-locked ERP analysis demonstrated the existence of an attentional effect indexed by a greater P1 amplitude in response to congruent rather than incongruent trials. Brain source analysis revealed that the congruency effect found in the P1 is generated by visual areas such as parahippocampal gyrus and the anterior fusiform gyrus.

Experiment 9: Adults

The aim of Experiment 9 was to test a control group of adults, results obtained recording manual reaction times replicated those previously obtained with saccadic latencies (Bardi et al 2015) and confirm that in adults walking direction could trigger orienting of visuo-spatial attention. In this experiment, ERP target locked component. were also recorded. Adults were tested with a cueing paradigm, the cue was a PLD of a human walker that was not predictive of the spatial position where the target would be appeared.

Participants

Fourteen undergraduate students selected from the Department of Psychology at the University of Padova took part at the experiment. One participant was discarded from the final sample because he decided to interrupt the testing session. Therefore, the final sample consisted of 13 undergraduate students (8 females; mean age = 24 years, SD= 1.12, range 22-26 years). All participants had no previous experience with eye movement studies and were naive to the experimental conditions and hypotheses of the study. All of them had normal or corrected-to-normal vision. The Ethical Committee of the Department of Developmental and Social Psychology of the University of Padova approved all the experimental procedures (Protocol number: 1956).

Stimuli

Cue stimulus was the same employed in Experiment 7 and 8. The target stimulus consisted of a white diamond and it was presented for 200 ms. At the beginning of each trial a fixation cross was presented in the center of a screen for 500 ms.

Apparatus and Procedure

The apparatus was the same employed in Experiment 7 and 8.

A cueing paradigm was employed (Posner, 1980; Bardi et al., 2015). The cue was shown for 1200 ms and, after a variable interval (range: 300-500 ms), the target stimulus was displayed for 200 ms at a peripheral spatial location (~10 degrees of visual angle from the center of the screen) either congruent or incongruent with the cue walking direction. Overall, 416 trials were presented and were equally divided between the experimental conditions (congruent and incongruent).

Written instructions were given to all participants. Subjects were required to press as fast and accurately as possible the left arrow on the keyboard when the target was presented on the left side and the right arrow on the keyboard when the target was presented on the right side, by using the index finger of the left and right hand respectively (i.e., choice detection task). Participants' manual Reaction Times (RTs) were recorded within a blank interval of 800 ms following the disappearance of the target stimulus. Participants were also instructed to not move the eyes and blink during the entire duration of each trial.

EEG recording and analysis

Continuous scalp EEG was recorded from a 128-channel HydroCel Geodesic Sensor Net (Electrical Geodesic, Eugene, OR) that was connected to a NetAmps 300 amplifier (Electrical Geodesic, Eugene, OR) and referenced on-line to a single vertex electrode (Cz). Channel impedance was kept at or below 100 KΩ and signals were sampled at 500 Hz. EEG data were pre-processed off-line using EEGLAB (Delorme & Makeig, 2004). As a first step, data segments were filtered using a 0.3–30 Hz band-pass filter and re-referenced to average reference. The EEG signal was segmented to 350 ms post-stimulus onset, with a baseline period beginning 100 ms prior to target onset and baseline corrected using mean voltage during the 100 ms pre-stimulus period.

Automated artifact detection was applied to the segmented data to detect individual epoched that showed >200µV voltage changes within the segment period.

For each participant, average waveforms were generated within each experimental condition (congruent and incongruent).

Results

Manual reaction times (RTs)

A paired T-test between mean RTs in congruent trials and mean RTs in incongruent trials was carried out. Adults' RTs were faster in response to congruent trials (M=262.3ms, SD=49.6) relative to incongruent trials (M=275 ms, SD=56.5), t(12)=-2.82, *p*=.014 (3.11).

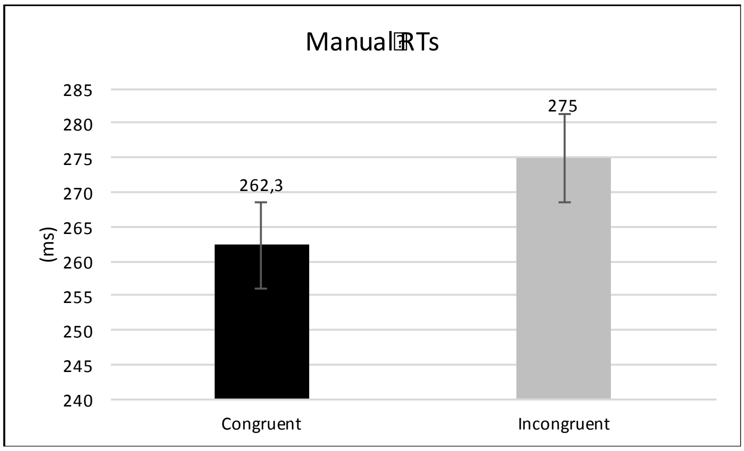

Figure 3.11 Average of saccadic reaction time of Experiment 9

Subsequently a repeated measure ANOVA with Age (3 months vs. 6 months vs. adults) as between participants factor and Congruency (congruent vs. incongruent) on reaction times recorded in Experiment 7, 8 and 9, was performed. The analysis revealed a main effect of the Age, F(1,2)= 1.27, $p < .001$, η^2_p=.049. Overall, with the increasing of the age, reaction time become faster (3 months M = 385.43, SE = 15.45; 6 months M

= 299.50, SE = 13.58 Adults M = 268.7, SE = 17.66). Was also found a main effect of Congruency, F(1,49) = 11.130, *p* < .002, η^2_p=.185, suggesting that reaction time was faster for congruent trials (M = 306.77, SE = 8.32) rather than incongruent (M =328.98, SE = 10.78). The interaction Age X Congruency did not reach the significance. The absence of interaction it might be due to the fact that in all samples a tendency to show faster reaction time for congruent rather than incongruent trials is present.

Target-locked P1 ERP component

Inspection of the grand-averaged waveforms revealed that the P1 ERP component was reliably elicited at target onset over occipito-parietal scalp sites. Based on visual inspection of both the grand-averaged and individual waveforms, 17 clusters of electrodes were created for the ERP target-locked analysis. According to 10-10 system of electrodes, clusters for O1, OZ, O2, I1, IZ, I2, PO7, PO8, PO9, PO10, P7, P8, P9, P10, TP7, TP8, CZ were created using the average of the three closest electrodes (Table 1). Based on grand-averaged data and individual data, peak and mean amplitude of P1 were extracted within a time window of 130 to 180 ms.

A paired T-test was separately carried out on peak and mean amplitude, for each cluster, between congruent and incongruent trials. The analyses revealed a significant effect as a function of congruency in temporo-parietal-occipital clusters. Specifically, P1 component, was larger for congruent (.65 µV) than incongruent trials (.38 µV) in TP8, *t*(12)=2.210 *p*=.047, in P10 *t*(12)= 2.221, *p*=.046 (congruent trials = 1.13 µV, incongruent trials = .59 µV), in P8 *t*(12)= 2.603, *p*=.023 (congruent trials = 1.02 µV, incongruent trials = .55 µV), and in PO10 *t*(12)= 2.645, *p*=.021 (congruent trials = 1.2

μV, incongruent trials = .48 μV). No significant effects were found on the mean amplitude (Figure 3.12).

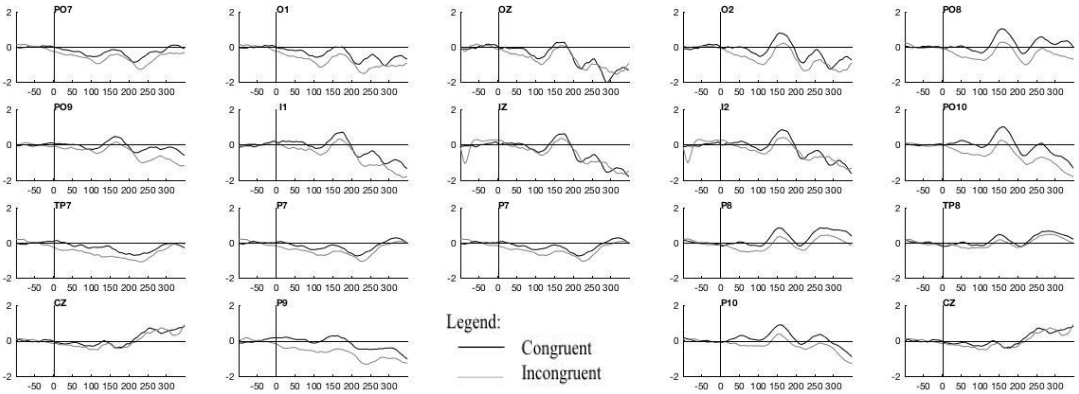

Figure 3.12 Grand Average plot in occipital and parietal clusters: response to congruent condition is represented in black, whereas response to incongruent condition is represented in grey

Overall, results of Experiment 9 confirm that walking direction triggers orienting of attention in adults' participant demonstrating that adults are faster to detect a peripheral target when it was presented in the spatial position congruent with walking direction rather than incongruent. ERPs evidence demonstrates that P1 target-locked component is modulated by the congruency relation between target and cue. Moreover, this effect is located in the contralateral clusters respect the side of targets' appearance, as also shown in 6-month-old infants (Experiment 8).

Conclusions

The goal of the experiments described in the present chapter, was to investigate the neural correlates of the attentional effect accompanying mechanisms of visual-spatial orienting triggered by upright biological motion walking direction. In addition, infants of 3 and 6 months of age were tested to describe a developmental trajectory of how our visual system use kinematic information conveyed by biological motion to orient attention in surrounding space.

To this aim 3- 6-month-old infants, were tested using a spatial cueing paradigm and EEG were recorded. Participants were presented with a spatially non-predictive PLDs of a human walker, followed by a peripheral target. Behavioral and ERPs data were analyzed as a function of the congruency relation between cue and target. As in the previous behavioral and EEG studies (i.e. Bardi et al., 2015; Farroni et al., 2000; Natale et al., 2016; Schuller e Rossion, 2001), in the present experiment only congruent and incongruent trials were presented. It is true that the absence of neutral trials renders it impossible to differentiate facilitatory effects produced by congruent trials from inhibitory effects produced by incongruent trials. For this reason, all the comparisons were carried out between congruent and incongruent trials. That means that I must confine myself to dealing of "attentional effects" in general, without distinguishing between facilitation and inhibition.

Overall, results of the three experiments demonstrate that the ability to extract walking direction from PLDs depicting a human walker seem to emerge at 6 months of age. This result confirms the previous behavioral findings that demonstrate that only at 6 months of age, infants were able to discriminate walking direction of human walker (Kuhlmeier et al., 2007). Moreover, ERPs results demonstrate that both adults and 6-month-old infants have a modulation of sensory component to the target as a function of the congruency relation with the cue.

Specifically, Experiment 7 demonstrated that 3-month-old infants seem not to be able to extract walking direction from PLDs depicting human walker. Behavioral results did not show any effect, that means that infants were not faster to orient their attention in congruent rather than incongruent trials. Also, ERP data did not reveal any modulation of P1 component related to congruency. The absence of effects both behavioral and in ERPs, might be interpreted as due to the fact that at 3 months of age infants are not still able to extract directionality information from a PLDs. These results are in line with previous behavioral evidence. Specifically, Berthental and colleagues (1985), demonstrated that infants starting from 5 months of age become sensitive toward the phase of dots. Phase of dots, is the spatio-temporal relation that characterized human motion. Walking direction, when a PLDs is presented walking on treadmill, is conveyed only from the phase of dots. Moreover, the absence of any modulation of attention triggered by biological motion walking direction can give rise to two possible interpretations. The first one might suggest that 3-months of age infants are not able to extract information of directionality from PLDs of a human walker. A second possible interpretation is that infants are able to extract the direction but they might not be able to use this information to orient their attention towards the surrounding space. Additionally, the absence of any effects also in ERPs components might depend on the fact that the system is too immature to show a modulation related to attentional mechanism in sensory components. As demonstrated by Richards (2000), by employing exogenous cues, the modulation of P1 components, due to the cue-target congruency relation, seems to emerge starting from 4.5 months of age.

Whilst the Experiment 7 did not show any effect, Experiment 8 showed that at 6 months of age infants are able to extract walking direction from a PLD and moreover, this information of directionality triggers an orienting of attention. Behavioral results of Experiment 8 replicated eye-tracking evidence coming from Bardi and colleagues (2015), confirming the role of upright biological motion walking direction in triggering visual-spatial orienting. More specifically, data on infants' behavior indicate that upright walking direction can facilitate saccade latencies in response to peripherally presented targets appearing at congruent relative to incongruent spatial locations. This advantage in saccade latencies might be explained by hypothesizing that the PLD walker triggers covert orienting of attention towards walking direction, yielding a facilitation of oculomotor responses to stimuli appearing at the attended location (Posner, 1980). Accordingly, behavioral results from this experiment confirm the hypothesis that upright biological motion walking direction of a human figure can influence mechanisms of visual-spatial orienting eliciting an overt orienting of attention.

In addition, the electrophysiological evidence of Experiment 8, showed that this processing advantage precedes the oculomotor responses even when the cue is not exogenous (i.e. a flash of light). From an ERPs perspective, the results of Experiment 8 support behavioral data, and demonstrate that the attentional effect occurs in the initial stages of visual processing. Specifically, target-locked ERP analysis demonstrated the existence of an attentional effect indexed by a greater P1 amplitude in response to congruent rather than incongruent trials. The P1 attentional effect indicates that the information provided by upright biological motion walking direction can yield a gain control or selective amplification of the sensory information in the extra-cortical visual pathways, improving the signal-to-noise ratio so that more information is extracted from relevant portions of the visual field. Importantly, the modulation of P1 component related to congruency obtained in this experiment by employing a central cue converges with evidence from developmental studies investigating the ERP correlates of covert shifts of attention triggered by pure exogenous cues in infants from 4 to 6 months (peripheral flashes of light) (Richards, 2000, 2005). These studies have reported an analogous enhancement of the P1 component for congruent relative to incongruent trials in the absence of overt shifts of fixation. As in these studies, also in Experiment 8 infants' fixation remained at central location until the target was presented.

Additionally, results coming from cortical source analysis show that infants manifest a facilitation effect and that the brain areas involved in the P1 congruency effect were parahippocampal gyrus and the anterior fusiform gyrus. The brain areas involved are visual areas: these data demonstrate that the facilitation effect has direct consequences on visual processing. The brain areas that are involved in the P1 congruency effect found in this study are located in parahippocampal gyrus and in the anterior fusiform gyrus and differ from those found in previous studies (Richards 200; Xie & Richards 2016). One possible interpretation between the results of Experiment 8 and those obtained in Richards' studies might be based on the different nature of the cues. Whereas in the study by Richards (2005) an exogenous cue was used, in the present study a central salient cue was used. The comparison between the two experiments, seem to suggest that when the ERPs at the scalp level converge, the nature of the cue stimuli affect the brain areas that origin the ERPs component. In accordance with the adult literature, social stimuli (i.e. eye gaze) seem to activate different brain areas compared to non-social stimuli (i.e. arrows) when they act as a cue in spatial cueing paradigms. For example, Hietanen and colleagues (2006), demonstrated that eye gaze activates a more specific area (e.g. temporal and parietal areas, i.e. STS) rather than arrows, which activate instead broader brain areas. Additionally, evidence has indicated that biological motion information is processed in the superior temporal sulcus (STS, Shiffrar, 1994).

Overall, behavioral and neural evidence coming from Experiment 8 converge in indicating that upright biological motion PLDs walking direction triggers automatic visual-spatial orienting in 6-month-old infants and that effects in oculomotor behavior are associated with functionally significant brain effects.

Finally, Experiment 9 demonstrate that also in adults walking direction can trigger a visuo-spatial orienting of attention. Behavioral findings confirm and extend the results found in Bardi and colleagues' study (2015) demonstrating that also with manual reaction times, adults were faster to detect congruent rather than incongruent targets. Intriguing, ERPs evidence demonstrate that also biological motion, as well as other social cues such as gaze, can orient attention toward the peripheral space, showing a modulation of P1 sensory component as a function of congruent relation between cue and target. Moreover, the effect in adults is localized in the temporo-parietal-occipital clusters. Adults' areas at the scalp level, are the same areas that become active in 6-month-old infants; this is might be an interesting starting point for localizing brain sources of P1 components either in adults.

Taken together, evidence described in this Chapter suggests that the ability to use walking direction to orient attention towards the peripheral space is an ability that emerges from 6 months of age. Specifically, 6-month-olds extract directionality and use it to orient attention towards the surrounding space whereas 3-month-olds infants do not utilize this cue. Unfortunately, I can not answer the question of whether or not they are able to extract directionality from the motion of dots. What I can argued is that the lack of congruency effect in 3-month-old infants resemble data obtained with eye gaze studies with 4-month-old infants3 that orient attention in the congruent location only on condition to perceive the translational movements of the eyes (Farroni, et al., 2000).

From a Neo/Neuro-constructivist perspective, the comparison between 3- and 6-month-old infants suggests that the ability to use information, such as directionality, to orient attention is an ability that emerges gradually during the development. A possible tentative explanation of the data might suggest that with increase of visual experience, due to the bidirectional interaction of these biases and the statistical regularities present in the specie-specific environment qualitative changes occur and at 6 months of age infants become able to use information of directionality to orient attention towards the peripheral space.

General Discussion

A central issue in developmental cognitive science is to understand how cognition develops and changes over time to reach an adult level of specialization. Determining the abilities with which infants come equipped into the world, their mechanisms for acquiring knowledge, and whether and how these abilities change as a function of development and experience is a challenging issue.

Since humans are intensely social creatures and they tend to rely on visual signals for communicating psychological dispositions, intentions and emotions, the study of how our system become specialized to detect and recognize others is an interesting field of research. A fundamental human social ability is the capacity to accurately detect and understand the intentional conduct of others, to anticipate their upcoming actions, and to appropriately adjust their own behavior (Gallese, 2009). Particularly, face and body motion represent primary social cues and it has been demonstrated that adults' brain has a specific neural network that supports detection and recognition of conspecifics and their actions (Adolphs, 2009).

From an ontogenetic perspective, the ability to read behavioral cues may be regarded as the fundamental precursors of more sophisticated social cognitive abilities (Gallese, 2009). Indeed, there is no doubt that before attributing goals, desires, dispositions to social agents, humans need to detect them in the environment and they need to use perceptual cues that allow them to discriminate animate *versus* inanimate objects. One of the most powerful cues that attract attention since birth is motion. Moreover, motion of living being has specific features that are not shared with motion of inanimate objects, such as self-propulsion and speed changes.

Considering motion as a fundamental feature that human species might use to detect others and within Neo/Neuro-constructivist theoretical framework, the purpose of my PhD dissertation was to test the role of kinematics in detection of social agents.

Particularly, my hypothesis that our visual system, since birth, possesses some attentional biases towards specific cues of motion that characterize animate entities seems to be confirmed by the data. In my view, these low-level biases are the building blocks, on which during development, infants and adults built their ability to infer other intentions. In this vein, the presence of the ability to orient attention on the basis of walking direction in 6-month-old infants and the absence of this effect in 3-month-old infants document that the experience during the first months of life plays a central role in shaping how our specie can use kinematics information, and also in shaping the system to become specialized in processing social information.

Using both the visual preference and the visual habituation techniques, the aim of the experiments presented in Chapter 2 was to investigate which are the perceptual motion cues towards which our visual system is sensitive since birth. According to evidence showing that both human infants, adults and even newly hatched chicks (Mascalzoni et al., 2010) seem to use self-propelled, change in direction, and speed changes motion cues to discriminate between animate and inanimate entities (Tremoulet and Feldman, 2000; Lou and Baillargeron 2010), collected data demonstrate that at birth also human newborns are sensitive self-propelled motion cues (Experiment 1; Experiment 2). Furthermore, results obtained from Experiment 3, 4, 5, and 6, demonstrate that also newborns are sensitive to speed change motion cues. Specifically, results of the experiments that tested newborns’ preference for speed changes demonstrated that newborns are not sensitive to speed changes in general but their attention is specifically attracted by the combination of acceleration and deceleration and only when these cues of motion follow a specific order of presentation. Newborns seem to have an innate predisposition towards acceleration-deceleration pattern of kinematics (Experiment 5), and they do not have a bias towards single speed changes (Experiment 3, and 4) or in a condition where the order of presentation was inverted (Experiment 6).

Data presented in Chapter 2 support the view that several vertebrate species, including humans, have a primitive bias toward detecting social agents and attending to and preferentially processing sensory information about other living entities (Carey, 2009) such as motion. Additionally, these results support the idea that animacy perception might be considered as a result of some low-level processes of the visual system (Rutherford, 2013). Newborns' sensitivity to detect visual cues of motion that belongs to animate and not to inanimate entities, does not imply that newborns have abstract concepts of animacy or agency (Carey, 2009).

The evidence found in the experiments described in Chapter 2, suggests that human species, since birth, have attentional biases that are pre-wired to detect cues of motion that belong to animate entities, such as self-propulsion and acceleration-deceleration pattern of motion. The sensitivity to perceptual cues of motion might be a sort of starting point to the development of the adults and infants' ability to extract social information from motion. In accordance with Carey (Carey, 2009) and Leslie (1994; Birò & Leslie 2007) the sensitivity towards perceptual cues of motion, that trigger animacy perception in adults, might be the bases on which during development, infants built the abstract concepts of intentional agency and mentalistic agency and also the bases on which humans build their ability to attribute attitudes and intention to others (mentalizing).

Taken together the evidence discussed in Chapter 2 supports the Neo/Neuro-constructivist assumption that states that at birth infants are equipped with constraints (i.e. attentional biases) that allow the system to have benefits such as focusing the cognitive system towards certain aspects of the environment or facilitating processing of certain types of inputs (Karmiloff-Smith, 1992). Specifically, the inborn sensitivity towards cues of motion such as self-propulsion and Acceleration Deceleration pattern of motion allows the system to focus attention towards these specific cues also when they are embedded in complex arrays.

Previous evidence demonstrates newborns and infants manifest a sensitivity toward these motion cues (i.e. Simion et al., 2008; Bardi et al., 2011) also when they are embedded in a complex array of dots. Moreover, evidence collected with adults demonstrates that when the complex array of dots depicts a walking human figure, adults can retrieve multiple social information form it such as walking direction (Bardi, et al., 2015). According to Troje and Johnson (Troje e Westhoff, 2006; Johnson, 2006), humans, as well other vertebrates, have an inborn mechanism that allow the system to detect other vertebrates based on motion. This mechanism, namely Perceptual Life Detector, would be an ontogenetically innate mechanism supported by subcortical structure. This mechanism would be deputed to be sensitive to the motion of legged vertebrate appearing in the visual periphery and to walking direction (Jonhson, 2006). Indeed, the oscillating movement of dots representing feet, is the best motion cues to detect and discriminate the direction of motion of vertebrate animals.

According to this model and in light of the evidence found in the experiments described in Chapter 2, the aim of the experiments described in Chapter 3 was to test whether the information of directionality conveyed by a complex array of dots, such as a PLD depicting a walking human figure, and conveyed by cues of motion such as self-propulsion and AD pattern of motion, can trigger orienting of attention in infancy. In Experiment 7 and 8 two samples of infants at different age levels were tested (i.e. 3- and 6-month-old infants) by using a visuo-spatial cueing paradigm (Posner, 1980; Bardi, et al., 2015) with a PLD of a human walker as central non-predictive cue. The saccade latencies were recorded coupled with ERPs target-locked responses to investigate the attention-related sensory gain effect to targets appearing at cued relative to uncued locations in a condition where the cue was represented by a human walking direction. Results of Experiment 7 demonstrated that 3-month-old infants did not show any behavioral effect, that means that infants were not faster to orient their attention in congruent rather than incongruent trials. Additionally, also ERP data did not reveal any modulation of P1 neural component related to congruency. The absence of any modulation of attention triggered by biological motion walking direction might be explained by to two possible interpretations. The first one might suggest that 3-months of age infants are not able to extract information of directionality from PLDs of a human walker whereas the second one is that infants might be able to extract the direction but they are not able to use this information as cue to orient attention. As demonstrated by Richards (2000) the absence of any effect also in the ERPs data might depend on the fact that at 3 months of age, the system is immature to show a modulation in sensory components related to an orienting of attention. Indeed, in the study done by

Richards (2000) only infants from 4.5 months of age showed a modulation of P1 sensory components related to orienting of attention.

In contrast, results of Experiment 8 demonstrated that 6-month-old infants can retrieve information of directionality from a PLD of human walker and they use this information to orient their attention towards the peripheral space. Six-month-old infants tested in Experiment 8, showed faster saccade latencies toward targets located in the congruent spatial position cued by walking direction rather than incongruent targets. These data confirm previous evidence that I found in a study that I conducted testing 6-month-old infants using an eye-tracking technique (Bardi et al., 2015). However, results presented in my previous work recorded only overt responses and for this reason does not demonstrate that the human motion can trigger orienting of attention in the absence of eye movements. ERPs data of Experiment 8 support behavioral data, and demonstrate that the attentional effect occurs in the initial stages of visual processing. Specifically, target-locked ERP analysis demonstrated the existence of an attentional effect indexed by a greater P1 amplitude in response to congruent rather than incongruent trials. The modulation of P1 components suggest that the information provided by PLDs of a human walker can yield a gain control or selective amplification of the sensory information in the extra-cortical visual pathways. Moreover, event though, according to Rizzolatti and colleagues' (1987) premotor theory of attention, the process of preparing the eyes to move is the mechanism by which endogenous spatial attention is engaged at target location before active stimulation, regardless of the nature, overt or covert, of the attentional shift, results of my previous work (Bardi et al., 2015) might be argued to be valid only for overt shifts of attention. Intriguing, the ERPs data found in Experiment 8 clearly demonstrate that biological motion can trigger an orienting of attention even before the eye movements (i.e. covert orienting of attention), extending the results found in my previous work and suggesting that walking direction can trigger either overt orienting of attention (Bardi et al., 2015) and also covert orienting of attention in infancy.

Experiment 9 replicate and extend previous findings obtained recording saccadic latencies showing that also in adults walking direction trigger a visuo-spatial orienting of attention (Bardi, et al., 2015). In the present version of the paradigm adults showed faster manual reaction times to detect targets that appeared in congruent rather than incongruent spatial position. More intriguingly ERPs data demonstrated that also in adults P1 sensory component is modulated by the cue-target congruency confirming that walking direction can yield a gain control or selective amplification of the sensory information in the extra-cortical visual pathways.

Taken together, evidence described in Chapter 3 suggests that the ability to use walking direction to orient attention towards the peripheral space is an ability that emerges from 6 months of age.

From a Neo/Neuro-constructivist perspective, the comparison between 3- and 6-month-old infants suggests that the ability to use information, such as directionality, to orient attention is an ability that emerges gradually during the development. The system starts with pre-wired predispositions to detect motion cues that are present in social agents. These initial predispositions (Chapter 2) allow the system to focus attention towards specific cues of motion such as self-propulsion and Acceleration Deceleration pattern of motion, either when they are presented isolated or when they are presented embedded in complex PDL arrays. The sensitivity since birth to these complex patterns of dots reproducing the movement of a vertebrate animal independently form the global shape configuration has already been documented. In Bardi and colleagues' study (2014) newborns showed a spontaneous preference for a display representing the legs of a walking hen, compared with an identical display in which individual dots trajectories were inverted, suggesting that since birth the focus of newborns' attention is tune towards the local dots that moves according to self-propulsion and AD pattern of motion.

The series of experiments presented in my PhD thesis was aimed to further explore the functional relevance of these predisposition during development and the consequences in term of cost and benefits to focus attention on motion cues. 6-month-old extract directionality and use it to orient attention towards the surrounding space whereas 3-month-olds infants do not utilize this cue. It might be plausible to hypothesized that, as well happened with other cues such as eye gaze (Farroni et al., 2000), at 3 months of age a translational movement is required to orient infants' attention. The PLDs stimuli employed in the experiments described in Chapter 3 were depicted a human that walks on the treadmill, so no perceiving translational movement was presented.

The Neuro-constructivist theoretical framework offers an interesting viewpoint for interpreting data presented in this thesis, and possibly guiding future research on the development of detection and recognition of social agents in human species.

Results of the experiments presented in Chapter 2 demonstrate that since birth humans are sensitive to certain motion cues that characterize motion of animate entities. These early predispositions to attend to specific type of movements may help infants to understand the complexity of the world in which they are embedded since birth, selecting and constraining the relevant stimuli to which focus attention. Additionally, previous work already demonstrated that newborns are sensitive to these cues of motion also when they are conveyed by complex arrays of dots that depicted walking figures (Simion et al., 2008; Bardi et al., 2011; 2014) or movements of body parts (Craighero, Lunghi, Leo, Ghirardi & Simion 2017). According to Frankenhuis and Barrett (2013), the detection and recognition of motion pattern when they are depicted as a human body or body parts might be facilitated by the action schemas that might be present in the infants' motor repertoire. Specifically, my proposal is that the perception of an array of dots depicting a walking human body or a grasping hand activates or should activate an action schema present in the motor repertoire and this schema seems to have an attention orienting function. In light of this, infants should find behaviors that trigger an action schema as the most interesting to look at. Moreover, the attention orienting function of action schemas helps the infants to organize behavior into appropriate categories, which are critical for learning.

Frankenhuis and Barrett's position is not in contrast with the hypothesis suggested by Troje and Westhoff (2006) and Johnson (2006) that states that humans possess a visual filter specific to motion of legged vertebrates. In my perspective, it is plausible to hypothesize that also the life detector is a mechanism supported by an action schema that is present in newborns' repertoire. It is known that at birth newborns have an innate reflex of stepping suggesting that the motor schema of walking is already present at birth. Additionally, others action schemas, such as grasping seems to be present in the newborn's motor repertoire. As demonstrated by Zoia and colleagues (2007), at 22 weeks of gestation fetuses are already able to adjust the acceleration of their own behavior (i.e. movement of the hand) in relation to the goal of the action suggesting that even during prenatal life humans have experience of goal-directed actions.

In light of this, it is plausible to hypothesize that at birth humans are endowed with both visual biases, such as attentional biases sensitive to cues of motion that characterize animate entities, and motor biases, such as action schemas that might be built based on the experience during the prenatal life and these schemas are activated when an action that is present in the motor repertoire is perceived. According to this hypothesis visual biases might be activated either when a single object is presented and it moves according to motion cues that define animate entities or when these cues of motion are presented in stimuli that follow the constraints of the body action schemas. Both visual biases and motor biases have an attention orienting function that constrain newborns and infants to focus attention to relevant stimuli (Frankenhuis & Barrett, 2013) and so filtering the accessible experience.

These biases, might be the bases on which infants identify conspecifics and are also the bases on which infants allocate attention towards the goal of an action (action priming; see figure 5.1).

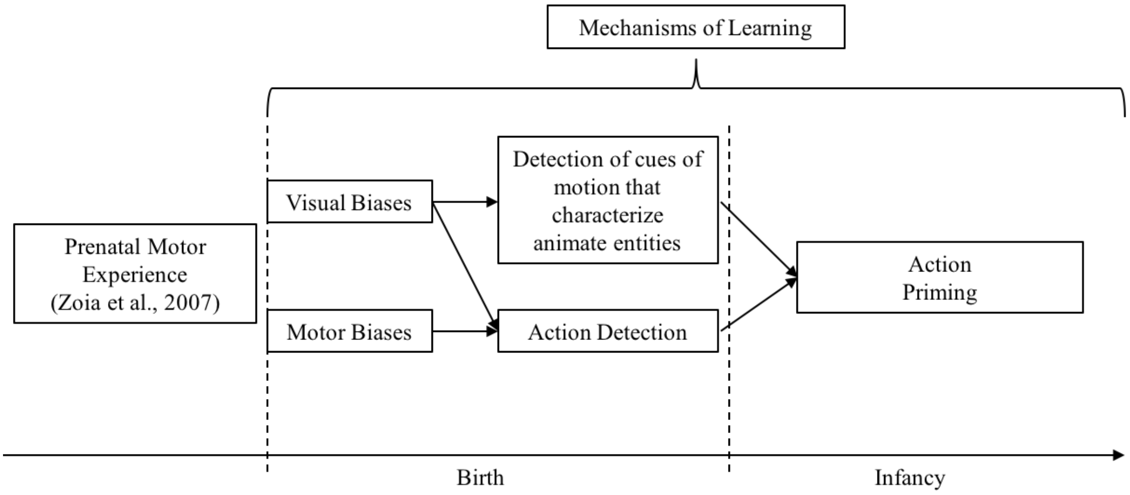

Figure 5.1 Schematic representation of the model of development of detection of social agents hypothesized based on the data presented in the present thesis.

According to Gredebäck and Daum (2015), once an agent is detected, observers adjust their attention in accordance with the direction of the other’s action. As demonstrated in literature, this attentional shift in the direction of others’ actions does not develop uniformly. The priming effect is strongest for action that infants can perform supporting the idea that action schemas play a central role in detection and recognition of others’ actions, since the first months of life. Specifically, a priming effect is present for static grasping hand at 5-7 months of life, (Daum & Gredebäck, 2011) and appears around 12 months of age for an image of a pointing hand (Daum, Ulber, Gredebäck, 2013). Moreover, when hands are moving, priming effect emerge earlier, around 4 months (Rohlfing, Longo, & Bertenthal, 2012) and at 6 months of age, the priming effect is present only when the action is moving according to the constraints of the human body (Natale et al., 2016). As for the action of walking, data presented in this thesis, seem to suggest that when no translational movement occurs visuo-spatial orienting towards the position triggered by the walking direction emerges only at 6 months of age (Chapter 3, Bardi et al., 2015). These biases represent the basis on which humans develop the ability to orient attention towards the goal of an action (action priming) followed by the ability to anticipate the goal of an action (action prediction), and to evaluate others' action by inferring intentions and disposition of other human being (action evaluation; Gredebäck & Daum, 2015; Figure 5.2).

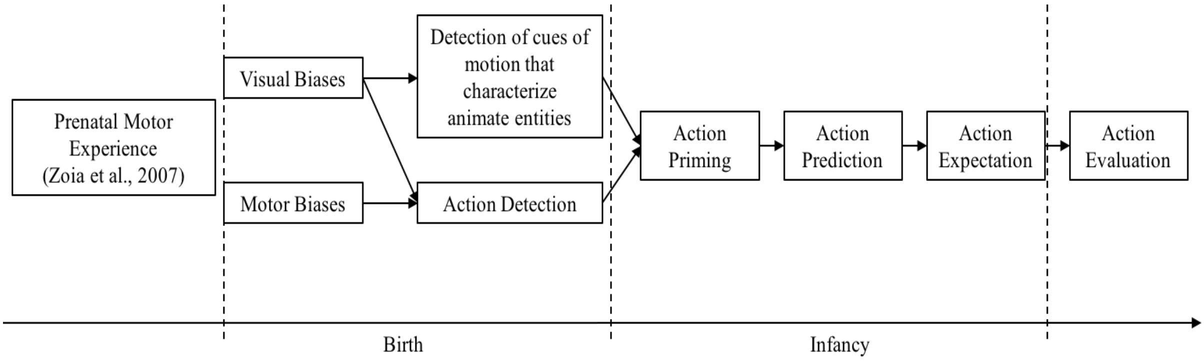

Figure 5.2 Schematic representation of the model depicted in the figure 5.1 and extended with the model of action understanding proposed by Gredebäck and Daum (2015).

Taken together the collected evidence seems to support the Neuro-constructivist assumption that the system, at the beginning, is endowed with attentional biases toward visual cues of motion and actions and, during development, through the experience and general learning mechanisms such as associative learning, the system became specialized to detect social agents, to discriminate agent-action-goals, to predict consequences of action (action prediction) and later to infer what an agent is planning to do that means to read the internal states of an agent (action evaluation).

This model of development, is in line with the embodied simulation theory (Gallese, 2014) which posits that an action is directly understood when the observer's motor system resonates in response to the observed action. Accordingly, it can be hypothesized that an innate rudimentary mirror neuron system (MNS) is already present at birth and can be flexibly modulated by motor experience and gradually enriched by visuomotor learning (Gallese, 2009). However, the evidence discussed in the present thesis does not directly proved the existence at birth of a functional mirror neuron system, but certainly supports the idea that humans are born with visual biases and motor biases that are the building blocks on which during the development and through mechanism of learning humans become specialized in detection, identification of conspecifics and later in reading their behavior.

As suggested, preferential attention to motion cues and, more specifically, to biological motion cues has been interpreted as a precursor of the capacity to attribute intentions to others (Frith and Frith, 1999). This observation raises important issues concerning developmental disorders with core social perceptual deficits, such as autism (Thompson and Hardee, 2008). Thus, according to Neo/Neuro-constructivist approach atypical development can, like typical development, be characterized as an adaptation to multiple interacting constraints, with the only difference that the constraints are different.

In light of this, to discover and to understand the constraints that shape typical development trajectory is an important step to investigate how different constraints shape atypical development.

References

Adolphs, R. (1999). Social cognition and the human brain. *Trends in Cognitive Sciences*, *3*, 469-479.

Adolphs, R. (2009). The social brain: neural basis of social knowledge. *Annual review of psychology*, *60*, 693.

Allison, T., Puce, A., & McCarthy, G. (2000). Social perception from visual cues: role of the STS region. *Trends in Cognitive Neuroscience*, 4, 267-278.

Baillargeon, R., & Wang, S. (2002). Event categorization in infancy. *Trends in Cognitive Sciences, 6*, 85-93.

Baker, R.K., Pettigrew, T.L., & Poulin-Dubois, D. (2014). Infants' ability to associate motion paths with object kinds. *Infant Behavior and Development*, *37*, 119–129.

Bakker, M., Daum, M. M., Handl, A., & Gredebäck, G. (2014). Neural correlates of action perception at the onset of functional grasping. *Social cognitive and affective neuroscience*, *10*(6), 769-776.

Bardi, L., Di Giorgio, E., Lunghi, M., Troje, N. F., & Simion, F., (2015). Walking direction triggers visuo-spatial orienting in 6-month-old infants and adults: An eye tracking study. Cognition, *141*, 112-120.

Bardi, L., Regolin, L., & Simion, F. (2014). The first time ever I saw your feet: Inversion effect in newborns' sensitivity to biological motion. *Developmental psychology*, *50*(4), 986.

Bardi, L., Regolin, L., & Simion, F., (2011). Biological motion preference in humans at birth: role of dynamic and configural properties. *Developmental Science*, *14*(2), 353-359.

Bassili, J.N. (1976). Temporal and spatial contingencies in the perception of social events. *Journal of Personality and Social Psychology, 33,* 680–685.

Bates, E. A., & Elman, J. L., (1993). Connectionism and the study of change. In M. Johnson (Ed.), *Brain development and cognition: A reader* (pp. 420-440). Oxford: Blackwell Publishers.

Bertenthal, B. I., & Pinto, J. (1994). Global processing of biological motions. *Psychological science*, *5*(4), 221-225.

Bertenthal, B. I., Proffitt, D. R., & Cutting, J. E. (1984). Infant sensitivity to figural coherence in biomechanical motions. *Journal of experimental child psychology*, *37*(2), 213-230.

Bertenthal, B. I., Proffitt, D. R., & Kramer, S. J. (1987). Perception of biomechanical motions by infants: implementation of various processing constraints. *Journal of Experimental Psychology: Human Perception and Performance*, *13*(4), 577.

Bidet-Ildei, C., Kitromilides, E., Orliaguet, J.-P., Pavlova, M., & Gentaz, E. (2014). Preference for point-light human biological motion in newborns: Contribution of translational displacement. *Developmental Psychology, 50(1),* 113–120.

Biro, S., & Leslie, A. M. (2007). Infants' perception of goal‐directed actions: development through cue‐based bootstrapping. *Developmental science*, *10*(3), 379-398.

Blake, R., & Shiffrar, M. (2007). Perception of human motion. *Annual review of psychology.*, *58*, 47-73.

Blakemore, S.J., Boyer, P., Pachot-Clouard, M., Meltzoff, A., Segebarth, C. et al. (2003). The detection of contingency and animacy from simple animations in the human brain. *Cerebral Cortex, 13,* 837–844.

Bonda, E., Petrides, M., Ostry, D., & Evans, A. (1996). Specific involvement of human parietal systems and the amygdala in the perception of biological motion. *The Journal of Neuroscience, 16*(11), 3737-3744.

Bosbach, S., Prinz, W., & Kerzel, D. (2004). A Simon effect with stationary moving stimuli. Journal of Experimental Psychology: *Human Perception and Performance, 30,* 39–55.

Brothers, L. (1996). Brain mechanisms of social cognition. *Journal of Psychopharmacology, 10,* 2-8.

Brothers, L. (2002). The social brain: a project for integrating primate behavior and neurophysiology in a new domain. *Foundations in social neuroscience*, 367-385.

Caramazza, A., & Shelton, J. (1998). Domain-specific knowledge systems in the brain: the animate–inanimate distinction. *Journal of Cognitive Neuroscience, 10*, 1–34.

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

Carrasco, M. (2011). Visual attention: The past 25 years. *Vision research*, *51*(13), 1484-1525.

Chang, D. H., & Troje, N. F. (2009). Characterizing global and local mechanisms in biological motion perception. *Journal of Vision, 9*(5), 8.

Cohen, L.B. (1972). Attention-getting and attention-holding processes of infant visual preferences. *Child Development, 43,* 869–879.

Craighero, L., Lunghi, M., Leo, I., Ghirardi, V., & Simion, F. (2016). Newborns' attention is driven by the translational movement. *Visual Cognition, 24*(9-10), 487-498.

Daum, M. M., & Gredebäck, G. (2011). The development of grasping comprehension in infancy: Covert shifts of attention caused by referential actions. *Experimental brain research, 208*(2), 297-307.

Daum, M. M., Ulber, J., & Gredebäck, G. (2013). The development of pointing perception in infancy: Effects of communicative signals on covert shifts of attention. *Developmental psychology*, *49*(10), 1898.

de Schonen, S. (2002). Epigenesis of the cognitive brain: a task for the 21st Century. In L. Backman and C. von Hofsten (Eds.), *Psychology at the turn of the millennium.* Hove, UK: Psychology Press, pp. 55–88.

Delorme, A., & Makeig, S. (2004). EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of neuroscience methods*, *134*(1), 9-21.

Di Giorgio, E., Lunghi, M., Simion, F., & Vallortigara, G. (2017). Visual cues of motion that trigger animacy perception at birth: the case of self-propulsion. *Developmental science*, *20*(4).

Dittrich, W. H. (1993). Action categories and recognition of biological motion. *Perception, 22,* 15–23.

Dittrich, W. H., Troscianko, T., Lea, S. E., & Morgan, D., (1996). Perception of emotion from dynamic point-light displays represented in dance. *Perception, 25(6),* 727-738.

Dittrich, W.H., & Lea, S.E. (1994). Visual perception of intentional motion. *Perception, 23,* 253–253.

Downing, P.E., Jiang, Y., Shuman, M., & Kanwisher, N. (2001). A cortical area selective for visual processing of the human body. *Science*, *293*, 2470–2473.

Driver IV, J., Davis, G., Ricciardelli, P., Kidd, P., Maxwell, E., & Baron-Cohen, S. (1999). Gaze perception triggers reflexive visuospatial orienting. *Visual cognition*, *6*(5), 509-540.

Farah, M. J., Rabinowitz, C., Quinn, G. E., & Liu, G. T. (2000). Early commitment of neural substrates for face recognition. *Cognitive Neuropsychology*, *17*, 117-123.

Farroni, T., Johnson, M. H., Brockbank, M., & Simion, F. (2000). Infants' use of gaze direction to cue attention: The importance of perceived motion. *Visual cognition*, *7*(6), 705-718.

Fodor, J. (1983). *The modularity of mind. An essay on faculty psychology*. Cambridge, MA: MIT Press.

Fox, R., & McDaniel, C. (1982). The perception of biological motion by human infants. *Science*, *218*(4571), 486-487.

Frankenhuis, W. E., & Barrett H. C. (2013) Design for Learning: The Case of Chasing. In M. D., Rutherford & V. A. Kuhlmeier (Eds.), *Social perception: Detection and interpretation of animacy, agency, and intention* (pp. 171-195). MIT Press.

Friesen, C. K., & Kingstone, A. (1998). The eyes have it! Reflexive orienting is triggered by nonpredictive gaze. *Psychonomic bulletin & review*, *5*(3), 490-495.

Frith, C. D., & Frith, U. (1999). Interacting minds—A biological basis. *Science, 286*, 1692–1695.

Gallese, V. (2009). Mirror neurons, embodied simulation, and the neural basis of social identification. *Psychoanalytic Dialogues*, *19*(5), 519-536.

Gallese, V., Rochat, M., Cossu, G., & Sinigaglia, C. (2009). Motor cognition and its role in the phylogeny and ontogeny of action understanding. *Developmental psychology*, *45*(1), 103-113.

Gelman, R. (1990). First principles organize attention to and learning about relevant data: number and animate-inanimate distinction as examples. *Cognitive Science*, 1, 79-106.

Gelman, R., Durgin, F., & Kaufman, L. (1995). Distinguishing between animates and inanimates: not by motion alone. In D. Sperber, D. Premack & A.J. Premack (Eds.), *Causal cognition: A multidisciplinary debate* (pp. 150–184). Oxford: Clarendon Press.

Gervais, W. M., Reed, C. L., Beall, P. M., & Roberts, R. J. (2010). Implied body action directs spatial attention. *Attention, Perception, & Psychophysics*, *72*(6), 1437-1443.

Gottlieb, G. (1992). *Individual development and evolution*. New York: Oxford University Press.

Gredebäck, G., & Daum, M. M. (2015). The microstructure of action perception in infancy: Decomposing the temporal structure of social information processing. *Child development perspectives*, *9*(2), 79-83.

Gredebäck, G., Melinder, A., & Daum, M. (2010). The development and neural basis of pointing comprehension. *Social Neuroscience, 5*(5-6), 441-450.

Greenough, W. T., & Black, J. E. (1992). Induction of brain structure by experience: Substrates for cognitive development. In M. Gunnar and C. A. Nelson (Eds.), *Behavioral developmental neuroscience. Vol. 24. Minnesota symposia on child psychology* (pp. 35-52). Hillsdale, NJ: Erlbaum.

Greenough, W. T., Black, J. E., & Wallace, C. S. (1987). Experience and brain development. *Child Development, 58,* 539-559.

Grossman, E. D., & Blake, R. (2001). Brain activity evoked by inverted and imagined biological motion. *Vision research, 41*(10), 1475-1482.

Grossman, E., Donnelly, M., Price, R., Pickens, D., Morgan, V., Neighbor, G., & Blake, R. (2000). Brain areas involved in perception of biological motion. *Journal of cognitive neuroscience*, *12*(5), 711-720.

Grossmann, T., & Johnson, M. H. (2007). The development of the social brain in human infancy. *European Journal of Neuroscience*, *25*(4), 909-919.

Gyulai, E. (2004). Considerations on perception of ‘‘animacy” in the motion of a single object. *Perceptual and Motor Skills*, *99,* 1014–1026.

Heider, F., & Simmel, M. (1944). An experimental study of apparent behavior. *American Journal of Psychology, 57,* 243– 259.

Hietanen, J. K., Nummenmaa, L., Nyman, M. J., Parkkola, R., & Hämäläinen, H. (2006). Automatic attention orienting by social and symbolic cues activates different neural networks: An fMRI study. *Neuroimage*, *33*(1), 406-413.

Hirai, M., Chang, D. H., Saunders, D. R., & Troje, N. F. (2011). Body configuration modulates the usage of local cues to direction in biological-motion perception. *Psychological Science*, *22*(12), 1543-1549.

Hirai, M., Saunders, D. R., & Troje, N. F., (2011). Allocation of attention to biological motion: Local motion dominates global shape. *Journal of vision*, *11*(3), 4-4.

Hooker, C. I., Paller, K. A., Gitelman, D. R., Parrish, T. B., Mesulam, M. M., & Reber, P. J. (2003). Brain networks for analyzing eye gaze. *Cognitive Brain Research, 17(2),* 406-418.

Horowitz, F.D., Paden, L., Bhama, K., & Self, P. (1972). An infant-control procedure for studying infant visual fixation. *Developmental Psychology, 7*, 90.

Johansson, G. (1973). Visual perception of biological motion and a model for its analysis. *Perception & psychophysics*, *14*(2), 201-211.

Johansson, G. (1976). Spatio-temporal differentiation and integration in visual motion perception. *Psychological research*, *38*(4), 379-393.

Johnson, M. H. (1993). Constraints on cortical plasticity. In M. J. Johnson (Eds.). *Brain Development and Cognition. A reader* (pp. 703-721). Cambridge, MA: Blackwell.

Johnson, M. H. (2000). Functional brain development in infants: Elements of an interactive specialization framework. *Child Development, 71*, 75 – 81.

Johnson, M. H. (2001). Functional brain development in humans. *Nature Reviews Neuroscience, 2*, 475-483.

Johnson, M. H. (2005). Subcortical face processing. *Nature Reviews Neuroscience, 6*, 766–773.

Johnson, M. H. (2006). Biological motion: a perceptual life detector? *Current Biology*, *16*(10), R376-R377.

Johnson, M. H. (2007). The social brain in infancy: A developmental cognitive neuroscience approach. In D. Coch, K.W., Fischer, & G. Dawson (Eds.), *Human Behavior, Learning and the Developing Brain: Typical Development*. (pp. 115-137). New York: Guilford Press.

Johnson, M. H. (2011). *Developmental cognitive neuroscience: An Introduction. Third Edition*. Blackwell Publisher.

Johnson, M.H., Grossman, T., & Farroni, T. (2008). The social cognitive neuroscience of infancy: Illuminating the early development of social brain functions. *Advances in Child Development and Behavior, 36,* 331-372.

Johnson, S.C. (2003). Detecting agents. *Philosophical Transactions of the Royal Society of London Series B: Biological Sciences, 358*, 549–559.

Johnson, S.C., Booth, A., & O'Hearn, K. (2001). Inferring the goals of a nonhuman agent. *Cognitive Development, 16*, 637–656.

Kaduk, K., Elsner, B., & Reid, V.M. (2013). Discrimination of animate and inanimate motion in 9-month-old infants: an ERP study. *Developmental Cognitive Neuroscience, 6*, 14–22.

Kanwisher, N. (2000). Domain specificity in face perception. *Nature Neuroscience, 3*, 759-763.

Karmiloff-Smith, A. (1992). *Beyond modularity: a developmental perspective on cognitive science.* Cambridge, MA: MIT Press.

Kellman, P. J. (1993). Kinematic foundations of infant visual perception. In C. Granrud, *Visual perception and cognition in infancy* (pp. 121-173). Hillsdale, NJ: Erlbaum.

Kingstone, A., Tipper, C., Ristic, J., & Ngan, E. (2004). The eyes have it. An fMRI investigation. *Brain and Cognition, 55*, 269–271.

Kozlowski, L. T., & Cutting, J. E. (1977). Recognizing the sex of a walker from a dynamic point-light display. Perception & Psychophysics, *21(6)*, 575-580.

Kuhlmeier, V. A., Troje, N. F., & Lee, V. (2010). Young Infants Detect the Direction of Biological Motion in Point-Light Displays. *Infancy*, *15*(1), 83-93.

Leslie, A.M. (1994). ToMM, ToBY, and agency: core architecture and domain specificity. In L. Hirschfeld & S. Gelman (Eds.), *Mapping the mind: Domain specificity in cognition and culture* (pp. 119–148). New York: Cambridge University Press.

Luo, Y. (2011). Three-month-old infants attribute goals to a non-human agent. *Developmental Science, 14,* 453–460.

Luo, Y., & Baillargeon, R. (2005). Can a self-propelled box have a goal? Psychological reasoning in 5-month-old infants. *Psychological Science*, *16*, 601–608.

Macchi Cassi, V., Valenza, E., & Simion F. (2012). *Lo sviluppo della mente umana*. Bologna: Il Mulino.

Mahon, B.Z., & Caramazza, A. (2009). Concepts and categories: a cognitive neuropsychological perspective. *Annual Review of Psychology, 60,* 27–51.

Mandler, J.M. (1992). How to build a baby: II. Conceptual primitives. *Psychological Review, 99,* 587–604.

Mandler, J.M. (2003). Conceptual categorization. In D. Rakison & L.M. Oakes (Eds.), *Early category and concept development* (pp. 103–131). Oxford: Oxford University Press.

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

Mather, G., & West, S. (1993). Recognition of animal locomotion from dynamic point-light displays. *Perception, 22*(7), 759-766.

Moore, D.G. (2012). Understanding of human motion, form and levels of meaning: evidence from the perception of human point light displays by infants and people with autism. In Slaughter, V., Brownell, C.A., *Early development of body representations* (pp. 122-145), Cambridge.

Natale, E., Addabbo, M., Marchis, I. C., Bolognini, N., Macchi Cassia, V., & Turati, C. (2017). Action priming with biomechanically possible and impossible grasps: ERP evidence from 6-month-old infants. *Social neuroscience*, *12*(5), 560-569.

Nelson, C. A., & Luciana, M. (Eds.) (2001). *Handbook of developmental cognitive neuroscience.* Cambridge, MA: MIT Press.

New, J., Cosmides, L., & Tooby, J. (2007). Category-specific attention for animals reflects ancestral priorities, not expertise. *Proceedings of the National Academy of Sciences, USA, 104*, 16598–16603.

Oostenveld, R., Fries, P., Maris, E., & Schoffelen, J. M. (2011). FieldTrip: open source software for advanced analysis of MEG, EEG, and invasive electrophysiological data. *Computational intelligence and neuroscience*, *2011*, 1.

Pavlova, M. A. (2012). Biological motion processing as a hallmark of social cognition. *Cerebral Cortex*, *22*(5), 981-995.

Pavlova, M., & Sokolov, A. (2000). Orientation specificity in biological motion perception. *Perception & Psychophysics*, *62*(5), 889-899.

Peelen, M. V., Heslenfeld, D. J., & Theeuwes, J. (2004). Endogenous and exogenous attention shifts are mediated by the same large-scale neural network. *Neuroimage*, *22*(2), 822-830.

Pelphrey, K. A., Morris, J. P., Michelich, C. R., Allison, T., & McCarthy, G. (2005). Functional anatomy of biological motion perception in posterior temporal cortex: an fMRI study of eye, mouth and hand movements. *Cerebral Cortex*, *15*(12), 1866-1876.

Pollick F.E., Paterson H. M., Bruderlin A., & Sanford A.J. (2001). Perceiving affect from arm movement. *Cognition. 82*, B51--B61.

Posner, M. I. (2016). Orienting of attention: then and now. *The Quarterly Journal of Experimental Psychology, 69*(10), 1864-1875.

Posner, M. I., 1980. Orienting of attention. Q. J. Exp. Psychol., *32*(1), 3-25.

Poulin-Dubois, D., Crivello, C., & Wright, K. (2015). Biological motion primes the animate/inanimate distinction in infancy. *PloS One, 10*, e0116910.

Poulin-Dubois, D., Lepage, A., & Ferland, D. (1996). Infants' concept of animacy. *Cognitive Development, 11*, 19–36.

Pratt, J., Radulescu, P.V., Guo, R.M., & Abrams, R.A. (2010). It's alive! Animate motion captures visual attention. *Psychological Science, 21*, 1724–1730.

Premack, D. (1990). The infant's theory of self-propelled objects. *Cognition, 36*, 1–16.

Puce, A., Allison, T., Bentin, S., Gore, J. C., & McCarthy, G. (1998). Temporal cortex activation in humans viewing eye and mouth movements. *The Journal of Neuroscience*, *18*(6), 2188-2199.

Puce, A., Allison, T., Gore, J.C., & McCarthy, G. (1995). Face-sensitive regions in human extrastriate cortex studied by functional MRI. *Journal of Neurophysiology, 74*, 1192–1199.

Quartz, S. R., & Sejnowski, T. J. (1997). The neural basis of cognitive development: a constructivist manifesto. *Behavioral and Brain Sciences*, 20, 537-596.

Rakison, D.H., & Poulin-Dubois, D. (2001). Developmental origin of the animate–inanimate distinction. *Psychological Bulletin, 127*, 209–228.

Rakison, D.H., Lupyan, G., Oakes, L.M., & Walker-Andrews, A.S. (2008). Developing object concepts in infancy: an associative learning perspective. *Monographs of the Society for Research in Child Development, 73 (1)*, i–127.

Regolin, L., Tommasi, L., & Vallortigara, G. (2000). Visual perception of biological motion in newly hatched chicks as revealed by an imprinting procedure. *Animal Cognition*, *3,* 53-60.

Richards J. E., & Xie W. (2015). Brains for all the ages: Structural neurodevelopment in infants and children from a life-span perspective. In: J. Benson (Ed) *Advances in child development and behavior, vol 48*. (pp 1–52) Elsevier: Philadephia.

Richards, J. E. (2000). Localizing the development of covert attention in infants with scalp event-related potentials. *Developmental psychology*, *36*(1), 91.

Richards, J. E. (2005). Localizing cortical sources of event-related potentials in infants' covert orienting. *Developmental science*, *8*(3), 255-278.

Richards, J. E. (2013). Cortical sources of ERP in prosaccade and antisaccade eye movements using realistic source models. *Frontiers in systems neuroscience*, *7*.

Rizzolatti, G., Fadiga, L., Matelli, M., Bettinardi, V., Paulesu, E., Perani, D., & Fazio, F. (1996). Localization of grasp representations in humans by PET: 1. Observation versus execution. *Experimental brain research, 111*(2), 246-252.

Rizzolatti, G., Riggio, L., Dascola, I., & Umiltá, C. (1987). Reorienting attention across the horizontal and vertical meridians: evidence in favor of a premotor theory of attention. *Neuropsychologia*, *25*(1), 31-40.

Rohlfing, K. J., Longo, M. R., & Bertenthal, B. I. (2012). Dynamic pointing triggers shifts of visual attention in young infants. *Developmental Science*, *15*(3), 426-435.

Rosa Salva, O., Farroni, T., Regolin, L., Vallortigara, G., & Johnson, M.H. (2011). The evolution of social orienting: evidence from chicks (Gallus gallus) and human newborns. *PLoS ONE, 6,* e18802.

Rosa Salva, O., Mayer, U., & Vallortigara, G. (2015). Roots of a social brain: developmental models of emerging animacy detection mechanisms. *Neuroscience and Biobehavioral Reviews, 50*, 150–168.

Rosa Salva, O., Regolin, L., & Vallortigara, G. (2012). Inversion of contrast polarity abolishes spontaneous preferences for face-like stimuli in newborn chicks. *Behavioural Brain Research, 228*, 133–143.

Rosa-Salva, O., Grassi, M., Lorenzi, E., Regolin, L., & Vallortigara, G. (2016). Spontaneous preference for visual cues of animacy in naïve domestic chicks: the case of speed changes. *Cognition, 157*, 49-60.

Rutherford, M. D. (2013). Evidence for Specialized Perception of Animate Motion. In M. D., Rutherford & V. A. Kuhlmeier (Eds.), *Social perception: Detection and interpretation of animacy, agency, and intention* (pp. 115-138). MIT Press.

Santos, N.S., David, N., Bente, G., & Vogeley, K. (2008). Parametric induction of animacy experience. *Consciousness and Cognition, 17,* 425–437.

Saxe, R., Tzelnic, T., & Carey, S. (2007). Knowing who dunnit: infants identify the causal agent in an unseen causal interaction. *Developmental Psychology, 43*, 149–158.

Scholl, B.J., & Gao, T. (2013). Perceiving animacy and intentionality: visual processing or higher-level judgment? In M.D. Rutherford & V.A. Kuhlmeier (Eds.), *Social perception: Detection and interpretation of animacy, agency, and intention* (pp. 197–230). Cambridge, MA: MIT Press.

Scholl, B.J., & Tremoulet, P.D. (2000). Perceptual causality and animacy. *Trends in Cognitive Sciences, 4*, 299–309.

Schuller, A. M., & Rossion, B. (2001). Spatial attention triggered by eye gaze increases and speeds up early visual activity. *Neuroreport*, *12*(11), 2381-2386.

Schuller, A. M., & Rossion, B. (2004). Perception of static eye gaze direction facilitates subsequent early visual processing. *Clinical Neurophysiology*, *115*(5), 1161-1168.

Schultz, J., Friston, K.J., O'Doherty, J., Wolpert, D.M., & Frith, C.D. (2005). Activation in posterior superior temporal sulcus parallels parameter inducing the percept of animacy. *Neuron, 45,* 625–635.

Senju, A., Johnson, M. H., & Csibra, G. (2006). The development and neural basis of referential gaze perception. *Social neuroscience*, *1*(3-4), 220-234.

Shi, J., Weng, X., He, S., & Jiang, Y. (2010). Biological motion cues trigger reflexive attentional orienting. *Cognition, 117,* 348–354.

Shiffrar, M. (1994). When what meets where. *Current Directions in Psychological Science,* 96-100.

Shipley, T. F. (2003). The effect of object and event orientation on perception of biological motion. *Psychological Science*, *14*(4), 377-380.

Simion F., & Leo, I. (2010). A neoconstructivistic approach to the emergence of a face processing system. In S. P. Johnson (Eds.). *Neoconstructivism: the new science of cognitive development* (pp. 314- 332). Oxford: Oxford University Press.

Simion, F., Di Giorgio, E., Leo, I., & Bardi, L. (2011). The processing of social stimuli in early infancy: from faces to biological motion perception. In O. Braddick, J. Atkinson & G. Innocenti (Eds.), *Gene expression to neurobiology and behavior: Human brain development and developmental disorders* (Progress in Brain Research, Vol. 189, pp. 173–193). Burlington, MA: Elsevier Academic Press.

Simion, F., Regolin, L., & Bulf, H., (2008). A predisposition for biological motion in the newborn baby. *Proceedings of the National Academy of Sciences, USA*, *105*(2), 809-813.

Simion, F., Valenza, E., Umiltà, C., & Dalla Barba, B., (1995). Inhibition of return in newborns is temporo-nasal asymmetrical. *Infant Behavior and Developmen*t, *18*(2), 189-194.

Sirois, S., Spratling, M., Thomas, M. S. C., Westermann, G., Mareschal, D., & Johnson, M. H. (2008). Precis of neuroconstructivism: how the brain constructs cognition. *Behavioral and Brain Sciences*, *31*, 321-356.

Slater, A., Earle, D.C., Morison, V., & Rose, D. (1985). Pattern preferences at birth and their interaction with habituation induced novelty preferences. *Journal of Experimental Child Psychology, 39*, 37–54.

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

Spelke, E. S. (1991). Physical knowledge in infancy: Reflections on Piaget's theory. In S. Carey & R. Gelman (Eds.). *The epigenesis of mind: Essays on biology and cognition* (pp.133-169). Hilsdale, NJ: Erlbaum.

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

Spelke, E.S. (2004). Core knowledge. In N. Kanwisher & J. Duncan (Eds.), *Attention and performance: Functional neuroimaging of visual cognition* (Vol. 20, pp. 29–56). Oxford: Oxford University Press.

Spelke, E.S., Phillips, A., & Woodward, A.L. (1995). Infants' knowledge of object motion and human action. In D. Sperber, D. Premack & A.J. Premack (Eds.), *Causal cognition: A multidisciplinary debate* (pp. 44–78). Oxford: Clarendon Press.

Stewart, J. (1984). Object motion and the perception of animacy. *Bulletin of the Psychonomic Society, 4*, 272.

Sugita, Y. (2008). Face perception in monkeys reared with no exposure to faces. *Proceedings of the National Academy of Sciences of the United States of America, 105*, 394-398.

Sumi, S. (1984). Upside-down presentation of the Johansson moving light-spot pattern. *Perception, 13*(3), 283-286.

Surian, L., & Caldi, S. (2010). Infants' individuation of agents and inert objects. *Developmental Science, 13*, 143–150.

Szego, P. A., & Rutherford, M. D. (2007). Actual and illusory differences in constant speed influence the perception of animacy similarly. *Journal of Vision, 7(12)*, 1–7.

Szego, P.A., & Rutherford, M.D. (2008). Dissociating the perception of speed and the perception of animacy: a functional approach. *Evolution and Human Behavior, 29*, 335–342.

Thompson, J. C., & Hardee, J. E. (2008). The first time ever I saw your face. *Trends in Cognitive Sciences, 12*, 283–284.

Tipper, C. M., Handy, T. C., Giesbrecht, B., & Kingstone, A. (2008). Brain responses to biological relevance. *Journal of Cognitive Neuroscience, 20*(5), 879-891.

Träuble, B., Pauen, S., & Poulin-Dubois, D. (2014). Speed and direction changes induce the perception of animacy in 7- month-old infants. *Frontiers in Psychology, 5*, 1141.

Tremoulet, P.D., & Feldman, J. (2000). Perception of animacy from the motion of a single object. *Perception*, *29*, 943–952.

Troje, N. F. (2002). Decomposing biological motion: A framework for analysis and synthesis of human gait patterns. *Journal of vision*, *2*(5), 2.

Troje, N. F. (2008). Biological motion perception. *The senses: A comprehensive reference*, *2*, 231-238.

Troje, N. F. (2008). Retrieving information from human movement patterns. In T. F. Shipley & J. M. Zacks (Eds.), *Understanding events: How humans see, represent, and act on events* (pp. 308–334). Oxford, England: Oxford University Press.

Troje, N. F., & Westhoff, C. (2006). The inversion effect in biological motion perception: evidence for a “life detector”?. *Current Biology*, *16*(8), 821-824.

Troje, N.F. (2013). What is biological motion? Definition, stimuli and paradigms. In M.D. Rutherford & V.A. Kuhlmeier (Eds.), *Social perception: Detection and interpretation of animacy, agency, and intention.* Cambridge, MA: MIT Press.

Valenza, E., Simion, F., Macchi Cassia, V., & Umiltà, C. (1996). Face preference at birth. *Journal of experimental psychology: Human Perception and Performance*, *22*(4), 892.

Vallortigara, G. (2012). Aristotle and the chicken: animacy and the origins of beliefs. In A. Fasolo (Ed.), *The theory of evolution and its impact* (pp. 189–200). New York: Springer.

Vallortigara, G., & Regolin, L. (2006). Gravity bias in the interpretation of biological motion by inexperienced chicks. *Current Biology*, *16*, 279–280.

Vallortigara, G., Regolin, L., & Marconato, F. (2005). Visually inexperienced chicks exhibit a spontaneous preference for biological motion patterns. *PLoS Biology, 3*, 1312–1316.

Waddington, C. H. (1975). *The evolution of an evolutionist*. New York: Cornell University Press.

Wang, L., Yang, X., Shi, J., & Jiang, Y. (2014). The feet have it: Local biological motion cues trigger reflexive attentional orienting in the brain. *NeuroImage, 84*, 217-224.

Werker, J. F., & Vouloumanos, A. (2001). Speech and language processing in infancy: A neurocognitive approach. In C. A. Nelson & M. Luciana (Eds.), *Handbook of Developmental Cognitive Neuroscience* (pp. 269-280). Cambridge, MA: MIT Press.

Xie, W., & Richards, J. E. (2017). The relation between infant covert orienting, sustained attention and brain activity. *Brain topography*, *30*(2), 198-219.