Influence of social hierarchies on infants' learning

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A los que alguna vez se han cuestionado
el orden social

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ABSTRACT

Humans are social animals living in groups and tending to organize themselves hierarchically. This social stratification influences individuals’ social interactions, as well as their cognitive processes such as learning. Because learning is essential during infancy, in this dissertation we aim to explore infants’ representation of social hierarchies and their influence on learning. A first set of studies showed that infants understand and can link from a third-party perspective two types of social hierarchies: those regulating conflicts (dominant-subordinate relationships) and those regulating collective actions (leader-follower relationships). A final study showed that infants are biased to learn from high-rank (dominant) individuals. We propose that infants' learning is influenced by high-rank agents because they are represented as leaders. We discuss the possible reasons behind human tendency to imitate high-rank agents (leaders) and we formulate a proposal of future studies addressing infants' representation of leadership.

RESUMEN

Los humanos son animales sociales que viven en grupos y que tienden a organizarse jerárquicamente. Esta estratificación social influye en las interacciones entre individuos, así como en sus procesos cognitivos, como por ejemplo el aprendizaje. Debido a que el aprendizaje es esencial durante la infancia, en esta tesis queremos explorar la representación infantil de las jerarquías sociales y su influencia en el aprendizaje. Un primer conjunto de estudios mostró que los bebés entienden y vinculan desde la perspectiva de un tercero dos tipos de jerarquías sociales: las que regulan conflictos (relaciones dominante-subordinado) y las que regulan acciones colectivas (relaciones líder-seguidor). Un último estudio demostró que los bebés están predispuestos a aprender de los individuos de alto rango (dominantes). Proponemos que el aprendizaje de los bebés está influenciado por los agentes de alto rango porque son representados como líderes. Planteamos las posibles razones detrás de la tendencia a imitar a los agentes de alto rango (líderes) y formulamos una propuesta de estudios futuros que aborden la representación infantil del liderazgo.

PREFACE

"[...] the clamour changed from the general wish for a chief to an election by acclaim of Ralph himself. None of the boys could have found good reason for this; what intelligence had been shown was traceable to Piggy while the most obvious leader was Jack. But there was a stillness about Ralph as he sat that marked him out: there was his size, and attractive appearance; and most obscurely, yet most powerfully, there was the conch."

Lord of the flies by William Golding (1962).

In his book, William Golding perfectly described one of the most pervasive behaviours in human relationships even at early ages: the tendency to organize groups hierarchically (Boehm, 2001; Flanagan, 1989). However, it is often hard to explain why and how we do it (Cheng, Tracy, Foulsham, Kingstone, & Henrich, 2013). Social hierarchies are often perceived as a burden to society. Why do we tend to organize ourselves in that way that usually benefits only a few individuals? (Holmes, 2009; Ward, 2004)

Several authors suggested that it is because it increases individual and group welfare (Halevy, Chou, & Galinsky, 2011). However, the advantages of social hierarchies only arise when the individuals who are at the top of the organization benefit the individuals who are at the bottom (Kakkar & Sivanathan, 2017). Theoretically, high-rank individuals can provide different types of benefits to the group members. These benefits can be related to better group coordination when the group members are led by an expert agent or related to access to the information possessed by high-rank agents. In return of these benefits, group members allow high-rank agents to collect more resources, reinforcing the social hierarchy between the group members (Gil-White & Henrich, 2001; Price & Van Vugt, 2014; Smith et al., 2016). This conceptualization of social hierarchies suggests that high-rank agents obtain and maintain their social status because low-rank agents allow them to as long as they obtain benefits (from them).

In the last years the interest on infants' capacity to represent social hierarchies has increased. These studies only addressed conflict situation in which one agent prevails and another agent loses (Mascaro & Csibra, 2012; Pun, Birch, & Baron, 2016; Thomsen, Frankenhuis, Ingold-Smith, & Carey, 2011). In the present dissertation, we extend the study of infant's representation of social hierarchies, focusing on two central questions. First, we investigate how infants understand agents' social power in absence of cues of physical dominance. Second, we analize how they represent leader-follower relationships in absence of conflict. Our final aim is to explore if there is a naive bias to learn from agents identified as high rank individuals. This dissertation tries to justify humans' tendency to organize themselves hierarchically as a consequence of the benefits that this type of organization provide. We show the existence of an early and naive readiness to represent such relationships and the existence of a learning bias towards the most successful individuals.

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1. INTRODUCTION

Humans as social animals learn from others. One fundamental issue is how do we determine who do we learn from. In the present dissertation we hold that already in early infancy humans are naively biased to learn from individuals identified as high-rank individuals. In order to address our research properly we explore two different research areas of human cognition: the infants' capacity to represent social hierarchies and its influence on learning.

First, we focus on the capacity of humans to learn; step by step we introduce the characteristics that differentiate us from the other animals, in particular, cultural learning. Then we present a brief review of features that have been shown to bias learning in infancy, such as informants' competence and group membership. Second, we discuss humans' tendency to live in groups and to organize themselves in a hierarchical manner. After defining the concepts of status, power and leadership, we review studies exploring these conceptual terms in early stages of development. At the end, we review the studies exploring how social hierarchies influence learning and present the research questions investigated in the present dissertation.

a. Learning process

i. Social Learning

The learning process, the capacity of acquiring new knowledge or modifying existing one, has always been a main topic of study in Cognitive Sciences. Even before the beginning of Psychology as a science, philosophers such as Socrates, Plato or Aristotle discussed the best way to teach and learn, and the different factors that influence both processes (Stonehouse, Allison, & Carr, 2011). Lev Vygotsky (1896- 1934) proposed the relevance of the social environment in the learning process (Vygotsky & Cole, 1978). His work mainly focused in psychological development since childhood, arguing that adults have to play the role of mediator in children's learning (Vygotsky, 1978). He strongly defended that social interactions are fundamental for a proper cognitive development and probably, he was the first psychologist to suggest the relevance that culture plays in human nature (van der Veer, 1996). Later, Albert Bandura in his Social Learning Theory (Bandura, 1971) held that learning is largely or even completely due to the observation, modelling and imitation of others' actions. Individuals could learn from the consequences of others' behaviours without the need of being themselves the ones rewarded or punished. He proposed the existence of a triadic interaction between the individuals, their behaviour and their environment.

Michael Tomasello, rescuing several ideas of Vygotsky, differentiated the concepts of social learning and cultural learning. He suggested that while social learning is based on learning from others, cultural learning is based in learning trough others (Tomasello, 2000; Tomasello, Kruger, & Ratner, 1993). Tomasello emphasized that in learning humans have the capacity of taking others' point of view, to understand their goals and to learn how they behave to achieve their goals. This capacity allows individuals to construct new knowledge over others' teachings and leads to cultural evolution. Cultural evolution refers to the idea that human culture changes over time in a Darwinian evolutionary process (Claidière, Scott-Phillips, & Sperber, 2014; Rindos et al., 1985;

Whiten, Hinde, Laland, & Stringer, 2011). Hence, only the functional and social relevant teachings will be transmitted through generations.

Cultural learning is selective because individuals do not learn everything from everybody indiscriminately (selectivity of encoding) and because not all that has been learned is used indiscriminately (selectivity of expression) (Boyd, Richerson, & Henrich, 2011; Heyes, 2017). Cultural evolution theories highlight the importance of different strategies that allow individuals to select the relevant information with the lowest cognitive cost. These strategies are known as cultural transmission biases or social learning strategies and they determine *when*, *what* and *from whom* individuals learn (Boyd et al., 2011; Joseph Henrich & McElreath, 2003; Laland, 2004; Mesoudi, 2016). We briefly summarize these strategies in the following.

Because the adaptive function of the cultural learning, individuals are biased to learn from others *when* are under uncertainty conditions, our behavior is not good enough to deal with the environment and asocial learning has more cost than social learning (Heyes, 2017; Laland, 2004). Content biases address *what* is the type of information individuals are biased to learn more easily and it is transmitted more often through generations (Boyd & Richerson, 1985; Joseph Henrich & McElreath, 2003). There are different reasons that make some content more relevant than another. First, reasons related with evolutionary ecological adaptations and survival, such as fear of dangerous animals such as spiders or snakes (LoBue & DeLoache, 2010; LoBue, Rakison, & DeLoache, 2010; Nairne, 2010). Second contents emotionally triggered are in general easier to learn (Eriksson & Coultas, 2014;

LaBar & Cabeza, 2006). Third, humans similarly to primates are biased to obtain social information, such as others' social features and relationships. (Dunbar, 1998, 2003; Mesoudi, Whiten, & Dunbar, 2006).

As social and cultural learners, humans inherently need other individuals to learn from. The predisposition to learn more from some individuals than from others is known as *context biases* (Wood, Kendal, & Flynn, 2013). These biases have been subdivided into frequency-dependent biases and model-based biases (K. Eriksson, Enquist, & Ghirlanda, 2007; Joe Henrich & Boyd, 1998). The first ones describe the tendency to learn from *who* behave like the majority of the members of their cultural environment. The second biases refer to the identity and properties of the models.

ii. Model-based biases during development

Many studies on model-based biases focus on infancy and childhood as it is the period when most information is learned in a social context (Wood et al., 2013). In their seminal work, Csibra and Gergely (2009) suggested that human communication evolved with pedagogical intentions. Humans have a high sensitivity to ostensive-referential cues that facilitate learning. For instance, many studies have shown that pointing, using ostensive cues through eye gaze, or using infant-directed speech facilitate infants' learning (Behne, Carpenter, & Tomasello, 2005; Cooper & Aslin, 1990; Senju & Csibra, 2008).

In-group members share our environment; hence they are more likely to have relevant knowledge to success in it (Begus, Gliga, & Southgate, 2016; Joseph Henrich & McElreath, 2003). Several studies have shown that infants prefer the information provided by their caregiver than the one provided by strangers (Corriveau et al., 2009). Similarly, children prefer information provided by familiar (non-genetically related) individuals than unfamiliar ones (Corriveau & Harris, 2009). When all the models are unfamiliar, cues indicating their social group membership are relevant. Different studies have shown that since very early on children prefer the information provided by individuals of the same social group (Begus et al., 2016; Begus, Gliga, & Southgate, 2017; Kinzler, Corriveau, & Harris, 2011; Kinzler & Liberman, 2017).

From the perspective of cultural evolution, the most successful individuals within a social group are the best candidates to be regarded as a model (Chudek, Heller, Birch, & Henrich, 2012). If cultural learning follows a Darwinian evolutionary process, to learn from the most competent individuals is the most adaptive strategy (Acerbi & Mesoudi, 2015; Boyd & Richerson, 1985; Gil-White & Henrich, 2001; Joseph Henrich & McElreath, 2003; Rindos et al., 1985). Several studies have addressed infants' and children's capacity to track the competence of different agents and their subsequent tendency to learn from them (Koenig & Harris, 2007; Tummeltshammer, Wu, Sobel, & Kirkham, 2014; Zmyj, Buttelmann, Carpenter, & Daum, 2010). These studies have shown that humans are not only biased to learn from individuals who explicitly are more competent but also from individuals who are perceived as more competent (Matsui, Yamamoto, & McCagg, 2006; Rakoczy, Hamann, Warneken, & Tomasello, 2010).

Individuals' success, real or perceived, is highly related with their social status. High-ranked individuals are those who properly deal with their physical and social environment achieving a better social position than their group peers (Fragale, Overbeck, & Neale, 2011; Koski, Xie, & Olson, 2015b; Kwaadsteniet & Dijk, 2010; Magee & Galinsky, 2008). The way individuals perceive their own and others' social status influences their cognitive processes, for instance, it has been shown that adults pay more attention to high-rank individuals (Dalmaso, Pavan, Castelli, & Galfano, 2012; Foulsham, Cheng, Tracy, Henrich, & Kingstone, 2010; Santamaría-García, Pannunzi, Ayneto, Deco, & Sebastián-Gallés, 2014; Zink et al., 2008). Similarly, several studies have explored how the social status of the models biases learning during childhood (Bernard et al., 2016; Castelain, Bernard, Van der Henst, & Mercier, 2016; Chudek et al., 2012; Fusaro & Harris, 2008; McGuigan, 2013). Before reviewing these studies we will discuss what is meant by social status is and how it is represented during development.

b. Social hierarchies

i. Social hierarchies an issue of concepts

Social hierarchy refers to group organizations based on different levels (Cheng, Tracy, & Anderson, n.d.; Koski, Xie, & Olson, 2015a; Magee & Galinsky, 2008). Despite the possibility of organizing groups in an egalitarian manner, social hierarchies seem to be quite ubiquitous across social animals (Boehm, 2001; Hand, 1986). Stratification of groups increases the general group's as well as individual's welfare (Halevy, Chou, & Galinsky, 2011). It has been suggested that "hierarchical" social order facilitates the resolution of fundamental problems that groups have to face daily, such as the collective decision making, the group locomotion or the intra-group coordination (Smith et al., 2016). However, such benefits depend on who occupies each position in the hierarchy.

The social status (or rank) refers to this position, and it is based on the comparison of one agent to the others regarding a valued social dimension, influencing the way individuals interact with each other (Halevy et al., 2011).

A by-product of social status is social power, and it refers to the amount of control of one agent in a valued social dimension. Social power may be the amount of influence and control of one agent regarding the behavior of other agents. Social power may also be the capacity of one agent to access and control specific limited resources; in this case the term social dominance can be used. The relationship between social status and social power is asymmetrical. Individuals who control specific resources have a high power over them; however, their social status will depend on the value that other individuals confer to those resources. In addition, controlling one resource does not involve controlling others. By contrast, holding a high status in a group consistently entails a high social power: the higher the social status of the individuals, the more resources they will control in general. Based on this conceptualization, social power is domain-specific while social status extends across different domains (Cheng, Tracy, Foulsham, Kingstone, & Henrich, 2013b; Fragale et al., 2011; Magee & Galinsky, 2008).

Social status and social power can be allocated by two means: dominance and prestige. Dominance is related to physical force, the use of fear and intimidation by an individual or group of individuals over the others. In dominant-subordinate relationships, the dominant (high-rank) agents are the ones who are able to exercise control over other agents and over the resources; while subordinate (low-rank) agents have no other option that to act according what dominant agents impose. Prestige is associated with the knowledge, skills and success that individuals are recognized for. Prestigious individuals, as a result of their knowledge or expertise in specific domains, are highly valuable for the group and provide benefits to the other members. In return of these benefits, group members confer to high competent agents a higher status by showing them respect and allowing them to get more resources (social power). Therefore, prestige-based hierarchies are constructed over the idea of the exchange of benefits (Cheng et al., n.d.; Cheng, Tracy, Foulsham, Kingstone, & Henrich, 2013a; Gil-White & Henrich, 2001; Kakkar & Sivanathan, 2017; Price & Van Vugt, 2014).

Several authors suggested that leaders-followers relationships are the result of dominant-subordinate relations (Kakkar & Sivanathan, 2017; Padilla, Hogan, & Kaiser, 2007; Vugt et al., 2007), while others defended that they are result of prestige-based relationships (Price & Van Vugt, 2014; Vugt et al., 2007). Leaders are defined as individuals who have a non-random differential influence on other agents' behaviors. They have an influence on what kind of collective behavior a group engages in, and how they coordinate to achieve their goals. Their role is contrasted to the "followers" role, whose behavior is usually influenced by the leaders. It has been shown a tendency to prefer dominant leaders under conditions of increase of uncertainty and threat. In contrast when group members can freely choose who to follow; they select the prestigious agents rather than the dominant ones due to the benefits they provide to the group (Anderson & Kilduff, 2009; Price & Van Vugt, 2014; Smith et al., 2016).

ii. Representation of social hierarchies during infancy

The pervasiveness of social hierarchies in humans and other social species suggests the existence of evolutionary shared basic mechanisms that allow their emergence and representation. Infants are the ideal population to explore such commonalities; studying how the understanding of social hierarchies during development evolves helps to differentiate between the naive capacities to represent them and the learned ones.

From an ontogenetic perspective, body size is crucial to allocate social status because it increases the probability of success in agonistic fighting contexts (Brey & Shutts, 2015; Buston, 2003; Lukaszewski, Simmons, Anderson, & Roney, 2016; Morgan et al., 2000). Thomsen et al. (2011) showed in their seminal work that 10-month-old infants consider the size of different individuals to predict their social power. These authors presented infants with two geometric figures of different size representing two social agents moving from one side to another in a platform. Next, both agents tried to cross the platform at the same time and their paths conflicted; at that moment the agents started to bump at each other repeated times, until one of them fell down and the other could advance. In the test phase, infants were presented two different outcomes, in one of them the bigger agent prevailed over the smaller one and in the other outcome the smaller agent prevailed over the bigger one. Using a violation of expectation paradigm, the authors found that infants expected the bigger agent to prevail over the smaller one.

Social alliances are also considered by adults and non-human primates in the allocation of social status. Individuals who have strong bounds with other members of the group have more social power (Newton-Fisher, 2004; Pietraszewski & Shaw, 2015; Pun, Birch, & Baron, 2016; Waal, 1986). Pun et al. (2016) showed that from 6 months of age, infants expect agents belonging to larger groups to prevail in a conflict situation. These authors used the same procedure as Thomsen et al. (2011), but they manipulated if the conflicting agents belonged to a group of 2 or 3 members. Their results suggest that numerical group size could be a more reliable or salient cue of social status than the size of the agents.

Mascaro and Csibra (2012) pointed to the importance of representing the stability of social hierarchies across time and context. They investigated infants' capacity to track which agent prevailed in a specific conflict situation and how infants used that information to predict future outcomes. In a first experiment, they presented 9 and 12 months-old infants an animated agent collecting different items. Shortly after, a second same size agent appeared trying to get the same items. In this conflict situation the second agent always prevailed, therefore that agent was considered the dominant one. In the test phase, the same two agents competed to collect a new type of item and two outcomes were presented to infants: in one outcome the dominant agent prevailed, while in the other the dominant agent did not. Results showed that 12 but not 9 months-old infants expected the dominant agent to prevail and to collect the item. These results suggested that 12 months-old infants inferred the hierarchical relationship of both agents on the basis of their interactions, and they considered such relationship a stable feature across time.

In a second experiment Mascaro and Csibra (2012) investigated if the agents' roles in a conflict situation were maintained and generalized through different non-related tasks. They presented 12 and 15 months-old infants with an animated agent who entered and remained still in an area delimited by walls. Next, a second agent appeared and pushed out the first agent. By “winning” the position inside the walls that agent was considered the dominant one. In the test phase, infants were presented with the same two agents competing to collect one item in an identical scenario as described in the previous experiment. Results showed that 15 but not 12 months-old infants expected the dominant agent to prevail and to collect the item. These results showed that 15-month-old infants consider that the social status of an agent is stable across different contexts.

The three studies described above addressed infants' representation of social hierarchies in agonistic contexts, in which agents conflicted in their goals and one agent prevailed by physical superiority. Nevertheless, social status can be allocated by means that do not explicitly entail the use of physical dominance, such as decision power, age or knowledge of the individuals. These other types of cues have been described in adults as well as non-human primates (Cheng et al., 2013a; Gil-White & Henrich, 2001; Koski et al., 2015b). To our knowledge, there are no studies investigating the origin of such capacities in infants before their second year.

Regarding older children, Charafeddine et al. (2015) showed that by 3 years of age, children are able to infer agents’ social status on the basis of their decision power, age, and resources allocation. In their procedure they presented two puppets in several scenarios with asymmetrical decision power, age or amount of resources. Children were asked to point which puppet they thought was the "boss". Children significantly selected the puppet with higher decision power, the older and the one who possessed more resources.

Brey and Shutts (2015) also asked children aged between 3 and 6 years of age which individual they thought was "in charge" between two agents displaying non-verbal cues associated with social status. They used videotaped records and static photographs of different agents displaying distinct postures (expansive vs. hunched), head positions (tilted up vs. down), eye-gazes (forward vs. down) and eyebrow positions (lowered vs. raised). Results showed that 5 to 6 year old children, but not younger children considered the posture, head orientation, and the eye-gaze as relevant cues to infer the social status of the agents.

Over and Carpenter (2015) used a similar methodology to test children's reasoning about individuals' social status and their role as a model or as an imitator. They presented to 4 and 5-year-old children videos of an individual consecutively imitating actions previously performed by another individual. When children were asked who they thought was the "boss", they tended to choose the imitated one. This study showed that children can represent social status on the basis of imitation (a form of social learning) from a third-party point of view. However, it does not answer the question if children's social learning is influenced by others' social status.

c. Social hierarchies and learning during development

i. Review of existing studies

How the social status of different agents influences children' learning has been established by different authors. McGuigan (2013) has shown that 5-year-old children over-imitate more easily high-status agents (head teacher) than low-status ones (class teacher). In their study, an agent taught 5-years-old children how to open a box in order to retrieve a reward. Critically, the model performed relevant (necessary) and irrelevant (unnecessary) actions to achieve the goal. Four different models could teach the children: the head teacher, the class teacher, a familiar experimenter and an unfamiliar experimenter. Results showed that children copied all the relevant actions independently of who was the model. Regarding the irrelevant actions, they copied significantly more of the actions performed by the head teacher. This study showed that actions performed by high status individuals bias children's learning.

Fusaro and Harris (2008) as well as Chudek et al. (2012) found that 4-years-old children tend to copy the actions of individuals who receive more visual attention from others (cue of prestige). Fusaro and Harris (2008) presented 4-years-old children two adult models naming in a different way an unfamiliar object. Critically, two adult bystanders approved one of model's name (via nods and smiles), but not the other's (via head shakes and frowns). In a test phase, children were asked different questions exploring their agreement with the models. Results showed that children supported the model who had received bystanders' approval, even in test trials in which the bystanders were not present. This study suggests that children tend to trust more easily agents receiving others' approval. However, these results can be interpreted in a different way because bystanders' approbation may had triggered a conformist bias (to learn from the majority) rather than a prestige bias (Joe Henrich & Boyd, 1998).

Chudek et al. (2012) performed a similar study but showing bystanders paying more attention, without showing cues of approbation, to one model than to the other. Two models received different amount of attention from other individuals when labeling unknown object, using unknown artifacts and showing their food preferences. Children learned from individuals who had received the greatest attention and that bias was stronger in the domain where the model was receiving the attention.

Children also are biased to trust individuals identified as high-rank agents in conflict situations. Castelain et al (2016) tested 4 to 6 years old children's bias to endorse testimony of physically dominant individuals. Using vignettes, they presented Mayan children several stories of two agents in conflicting situations. One of the agents (the dominant one) prevailed by using physical force over the other agent (the subordinate agent). Next, both agents claimed conflicting testimonies regarding where a hen could be found, and children were asked who they trusted more. Results showed a bias to support the testimony of the dominant agent. In following experiments, the authors manipulated the way in which the agents performed theirs claims. Results showed that children supported the testimony of the subordinate agent if he used a stronger argument, that is, if he said he had seen where the hen went; than the one used by the dominant agent, that is, without justifying why he knew where the hen went (Mercier, Bernard, & Clément, 2014; Mercier & Sperber, 2011). This study showed that children, even from non-Western Societies, tend to trust agents with high social status.

Bernard et al. (2016) found a similar pattern in 3-years-old children from Western societies using a similar procedure. In a first experiment, they presented children several scenarios where two agents were in conflict trying to collect different items. In these scenarios, one of the agents always prevailed. Next, both agents cued different locations to find a lost pet and labeled an unfamiliar object in different ways. In both cases children significantly endorsed the testimony of the dominant agent. In a second experiment, agents’ dominance was allocated by their decisional power (who decided where furniture would be placed in a new house) and not by their physical power. These results supported and extended the conclusions put forward by Castelain et al. (2016) in several ways: first by exploring the influence of the non-physical dominance in the endorsement of testimony, and second, by showing the bias towards high-rank agents' statements in younger children.

ii. Goals and empirical strategy of the present dissertation

The studies just reviewed showed that children from 3 years of age are biased to copy individuals identified as high-rank agents; however as reviewed the capacity to recognize others' social status emerge earlier in development, during the second year of life. In the present dissertation we aim to investigate if infants' learning is influenced by models' social status as soon as they can represent this type of social relationships. The empirical part of this thesis is structured in two experimental sections.

The first experimental section is composed by three studies addressing infants' representation of social hierarchies. Because human social hierarchies are not based only on the physical properties of the agents, in our first study extended the results of Mascaro and Csibra (2012) in the absence of cues of physical dominance. We tested if the sole presentation of agents' social power is enough to allow infants to make predictions in agonistic contexts. In a second study we explored infants' capacity to represent social hierarchies based on the concept of leadership. In such relationships, high-rank agents (leaders) influence low-rank agents' (followers) behaviour (Price & Van Vugt, 2014; Smith et al., 2016). A third study, links both types of social hierarchies by investigating how different ways of prevailing in conflict situations results in different types of leadership roles (Fragale et al., 2011; Price & Van Vugt, 2014). The second experimental section presents a study studying how the social status of an agent can influence infants' learning in a non-linguistic learning task (Tummeltshammer, Wu, Sobel, & Kirkham, 2014).

2. EXPERIMENTAL SECTION I

a. Infants' representation of social hierarchies in absence of physical dominance

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ABSTRACT

Social hierarchies are ubiquitous in all human relations since birth, but little is known about how they emerge during infancy. Previous studies have shown that infants can represent hierarchical relationships when they arise from the physical superiority of one agent over the other, but humans have the capacity to allocate social status in others through cues that not necessary entail agents' physical formidability. Here we investigate infants' capacity to recognize the social status of different agents when there are no observable cues of physical dominance. Our results evidence that a first presentation of the agents' social power in a resource allocation task is enough to allow infants predict the outputs of their future. Nevertheless, this capacity arise later (at 18 month-olds but not at 15 month-olds) than showed in previous studies, probably due the increased complexity of the inferences needed to make the predictions.

INTRODUCTION

The recognition of the social status - the rank that someone has in a group- is essential in human relations. It facilitates our interactions with others (Halevy, Chou, & Galinsky, 2011; Kwaadsteniet & Dijk, 2010; Price & Van Vugt, 2014; Smith et al., 2016a) and modulates our cognitive processes. For example, task performance differs depending on the social rank of the person we interact with and we pay more attention to high-ranked agents than to those of low rank (Foulsham, Cheng, Tracy, Henrich, & Kingstone, 2010; Santamaria-Garcia, Pannunzi, Ayneto, Deco, & Sebastian-Galles, 2013; Zink et al., 2008). Most of these phenomena have been reported with adults, however humans are immersed in social groups since birth and in the recent years researchers have started to increase their interest in how the perception of social hierarchies can modulate other cognitive processes in infancy.

The capacity to recognize hierarchical relations between different social agents originates during the first year of life. Thomsen, Frankenhuis, Ingold-Smith, & Carey (2011) showed that 10-month-old infants consider the size of an agent as an index of status. They presented the infants with a context in which two agents, represented by geometric figures of different sizes were individually able to go from one side to the other of a platform. However, when the two agents tried to cross the platform at the same time, their paths conflicted; at that moment the agents started to bump each other repeated times, until one of them fell down and the other could advance. Infants could see two scenarios: in one of them the bigger agent prevailed over the smaller one and in the other one the smaller agent prevailed over the bigger one. Using a violation of expectation paradigm, Thomsen et al. (2011) found that infants expected the bigger agent to prevail over the smaller one. These results evidenced that already at 10 months infants had understood the conflict situation between both agents and made predictions about which of the agents was more likely to cross the platform on basis of their physical size.

Mascaro and Csibra (2012) investigated infants' capacity to infer the social status of two interacting agents regardless of their observable physical properties. To address this issue, they presented 9 and 12 months-old infants with one agent (agents were represented by colored geometric figures) who was on one side of the screen, collecting different items one by one from the center of the screen. When the agent had collected a total of three items and stored them in its side, a new agent of a different shape and color, but similar size, appeared on the opposite one. At this point, every time the first agent tried to pick up a new item, the new agent moved rapidly to the center and collected it. Thus, in the conflict situation the new agent always prevailed over the first one. In the test phase, the same two agents competed to collect a new type of item and this time they moved simultaneously to get it. Results showed that 12 but not 9 months-old infants expected the second agent to prevail and to collect the item. These results could suggest that infants inferred the hierarchical relationship of both agents on the basis of their interactions and they considered it as a stable feature across time. Nevertheless, the same authors pointed to the existence of important limitations to this study "because of the similarity between the familiarization and the test situations, infants may have used simple strategies. For example, they may have built up a rule such as "when agents A and B are present, agent A gets the object" (Mascaro and Csibra, 2012, p. 6863). In a second experiment the authors investigated if the agents' roles in a conflict situation were maintained and generalized through different non-related tasks. To this end, they presented 12 and 15 months-old infants with an agent who entered an area delimited by walls to remain there. Then, a second agent appeared and by pushing out the first agent "won" the position inside the walls. In the test phase, infants were presented with the same two agents competing to collect one item in an identical scenario as described for the previous experiment. The results showed that the 15 months-old infants but not the 12-month-olds, were expecting that the (same) agent who had won the position inside the walls was the one who collected the item. These results confirmed that by 15 months, infants consider the social status of an agent stable across very different contexts when physical dominance is present.

A critical feature of Thomsen et al., (2011) and Mascaro and Csibra (2012) studies was the use of physical formidability to determine social status. In the two investigations, there was a goal shared by two agents that could not be achieved by the two of them at the same time. In Thomsen et al. (2011) the bigger agent, the physically most powerful one was who crossed the platform. In the second experiment of Mascaro and Csibra (2012), the agent who pushed stronger was also the one getting the desired goal. Although Mascaro and Csibra (2012) interpreted their results as the emergence of the social status in general, the type of interactions agents was engaged in, involved a relationship of physical dominance. However, humans establish social status through cues that do not entail the use of physical dominance such as the knowledge, skills and success that someone shows to others and that others recognize in her (Cheng, Tracy, Foulsham, Kingstone, & Henrich, 2013b; Gil-White & Henrich, 2001).

Here we want to investigate infants' capacity to represent the social status of one individual across different domains when no cues of physical dominance are presented. We consider that the presentation of the agents' social power, defined as their capacity to control limited resources (Fragale, Overbeck, & Neale, 2011; Magee & Galinsky, 2008), is enough to allow infants to make predictions about the future interactions of the agents in non-related contexts. However, due the lack of an observable and explicit property that justify why one agent prevails over the other, we hypothesized that the representation of the hierarchical relationship might emerge later in infancy in comparison of previous study.

We recorded 15- and 18-month-olds' eye gaze while watching silent videos of two physically similar agents competing to fulfill the same goal of grabbing a teddy bear. The same (high-ranked) agent always prevailed over other (low-ranked) agent after some interactions only involving eye contact (Brey & Shutts, 2015). Critically, to avoid Mascaro and Csibra's (2012) criticisms to experiment 1, first we presented infants how each agent was able to fulfill the same goal separately. Later, the same agents competed in a novel situation where the goal was to seat on an armchair. For half of the infants, the same agent (the high-ranked) kept winning (*Congruent output*) whereas for the other half, the previously lower-ranked agent won (*Incongruent output*). The selection of the age was determined by the results of Mascaro and Csibra (2012) who only observed generalization of social status across tasks in 15 months old.

METHODS

The research reported in this manuscript has been conducted in accordance with the principles expressed in the Declaration of Helsinki and approved by the local ethical committee. All parents signed an informed consent for their infants to participate in this study.

Participants

The sample size was determined according to previous studies (Mascaro & Csibra, 2012; Thomsen et al., 2011). Participants were recruited by visiting maternity rooms at private hospitals, the Hospital Quirón and the Clínica Sagrada Família in Barcelona, Spain. All participants were healthy, full-term infants (> 37 Weeks of gestation).

Sixty-four infants were retained for the analysis. Thirty-two were 15 months-old, 16 (9 boys) participated in the congruent output (M = 464, SD = 14 days) and 16 (8 boys) participated in the incongruent output (M = 471, SD = 11 days). Thirty-two were 18-month-old, 16 (8 boys) participated in the congruent output (M = 550, SD = 11 days); and 16 (10 boys) participated in the incongruent output (M = 560, SD = 33 days).

Forty-two additional infants were tested but not included in the sample due to: technical error or experimental error (n = 1; 18-month-old), fussiness, crying or parental interference (n = 7; 4 of 18-month-old), less than 50% of eye-tracker data obtained during the whole experiment (n= 14; 9 of 18-month-old), lack of data at one conflict-trial during the familiarization (n= 3, 1 of 18-month-old), lack of data at the conflict-trial during the test phase (n= 20; 10 of 18-month-old).

Stimuli and procedure

The experiment was divided in three phases: Preference (a1, a2, a3), Familiarization (individual contexts: b1 and b2; conflict context b3) and Test (ca, c2 and c3). See the main text for a full description.

Preference tests (a1, a2 and a3 in Fig 1)

A picture of each agent's face was used to measure infants' preference for each agent. Both agents' pictures were presented at the same time during 5 seconds. Each agent appeared in the same side where they appeared in the rest of the movies.

Familiarization phase (b1, b2 and b3 in Fig 1)

All the videos started showing the same scenario. A teddy-bear was on a table located in the middle of an empty room.

The familiarization phase was subdivided in two parts. In the first one (individual contexts, b1 and b2 in Fig 1), each agent entered the scene from one of the sides and greeted to the camera by waving her hand and smiling (7 s). Next, she looked at the teddy-bear and approached to get it. Finally, she moved forward smiling (5 s). Altogether the video duration was 12 s. First we presented the high-ranked agent and next the low-ranked one.

In the second part (conflict context, b3 in Fig 1) both agents appeared from their corresponding sides and simultaneously greeted to the camera (7 s). Next, they looked at the teddy-bear and approached it at the same time. During the following 5 seconds, both agents performed the same sequence of actions in a synchronized way. First, they touched the teddy-bear and then they looked at each other, this action was repeated twice. Then, the high-ranked agent took the teddy-bear and moved forward smiling (3 s). Then, the low-ranked agent stepped back and bended her head (4 s).

Test phase (c1, c2, c3.1 and c3.2 in Fig 1)

In this phase, the videos started showing an armchair in the middle of an empty room. The sequence of movements paralleled those of the familiarization phase, with two exceptions. First, the agents sat down in the armchair instead of grabbing the teddy-bear. And second, there were two possible outcomes, labeled it critical part (framed screenshots at in Fig 1), at the end of the conflict context. In the congruent output, the high-ranked agent sat down on the armchair (conflict context, c3.1 in Fig 1), and in the incongruent output, the low-ranked agent sat down on the armchair (conflict context, c3.2 in Fig 1). Half of the infants saw the congruent output, the other half the incongruent output. In this phase children only saw the sequence of the videos once.

Apparatus

Infants were tested in the “Laboratori de Recerca en Infància”, from the Center for Brain and Cognition at Universitat Pompeu Fabra, Barcelona. Infants sat on their caregiver’s lap at approximately 65 cm from the screen in a sound-attenuated room. The session was controlled through a camera (Sony HDR-HC9E). All stimuli were presented using Matlab’s Psychtoolbox-3 software on a 23” screen and gaze was measured using a Tobii TX300 near infrared eye tracker, recording at a frequency of 300 Hz. Before each recording the eye tracker was calibrated using five-points of reference. Videos were presented in a full screen with a resolution of 1920 x 1080 pixels in a 23” screen; photos were 15 x 10 cm and they were presented at 5 cm from the center of the screen. Between each stimuli (video and images), a fixed cross at the center of the screen was presented for 0.5 seconds and the total duration of the experiment after the calibration was approximately 2 minutes and 30 seconds.

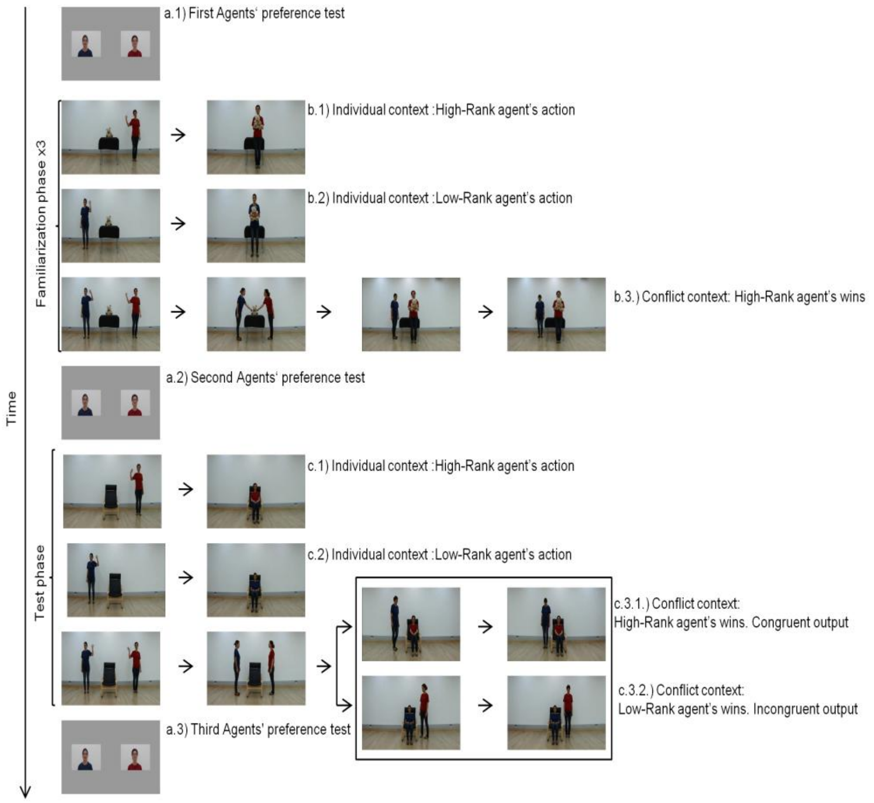

Fig 1 Experimental procedure. The study was composed by two main phases: familiarization and test. Preference for each agent was measured at three time points during the experiment: at the beginning of the experiment, after the familiarization phase and at the end of the experiment.

RESULTS

The main analysis focused on the conflict context on the test phase (c3.1 and c3.2 in Fig 1). We defined two time windows according to the actions of the agents. The first time window labeled as "common" started at the beginning of the video until one of the agents took the teddy-bear or sat on the armchair (12 s). The second time window called "critical" (framed screenshots at c3.1 and c3.2 in Fig 1.) started when one of the agents sat on the armchair and lasts until the end of the video (7 s). We calculated the proportion of Total Looking Time to the Screen (TLTS) by dividing the time infants spent looking at the screen during one of these time windows by the total duration thereof. This calculation was made for both congruent and incongruent outputs (see Fig 2 and Table 1).

A mixed repeated measure ANOVA was computed to analyze the Total Looking Time to the Screen (TLTS) based on three factors: Age (15m.o. and 18 m.o.) and Congruency (Congruent and Incongruent) as between factors and Part (Common and Critical) as within factor. The ANOVA showed a marginal double interaction between Congruency and Part ($F (1, 60) =3.991$, $p=0.05$, $\eta^2_p= 0.062$) and a triple interaction between Age, Congruency and Part ($F (1, 60) =4.117$, $p=0.047$, $\eta^2_p= 0.064$).

The triple interaction was unpacked by performing different ANOVAs for each age group separately, using Congruency and Part as factors. The interaction was only significant for 18-month-old infants ($F (1, 30) =6.478$, $p=0.016$, $\eta^2_p = 0.693$). As expected, there were no differences in the Common part between Congruent and Incongruent outputs. However, 18-month-old infants in the

Incongruent Output looked longer to the screen than those in the Congruent one (t (15.609) =2.481, p=0.025, 95% CI [-0.265, -0.020], d= 0.91, Levene's test indicated unequal variances F= 14.829, p= 0.001, so degrees of freedom were adjusted from 30 to 15.609).

For 15-month-old infants the ANOVA showed a main effect of Part (F (1, 30) =7.176, p=0.012, partial η2= 0.736), due the decreasing of TLTS between the Common and the Critical Part (t (31) =2.723, p=0.011).

No differences were found when comparing age and congruence in any of the other stimuli presented during the experiment, neither in the preference tests. Therefore all groups behaved the same way until the critical part on the conflict context on the test phase.

Table 1. Mean and 95% confidence interval of the Total Looking Time to Screen at the conflict context on the test phase across the two main parts.

		Common Part Mean [CI]	**Critical part** Mean [CI]
15 m.o.	**Congruent Output**	0.921 [0.865; 0,977]	0.869 [0.783; 0.955]
	Incongruent Output	0.918 [0.842; 0.994]	0.865 [0.762; 0.969]
18 m.o.	**Congruent Output**	0.907 [0.847; 0.967]	0.839 [0.717; 0.960]
	Incongruent Output	0.922 [0.830; 1.014]	0.982 [0.964; 0.999]

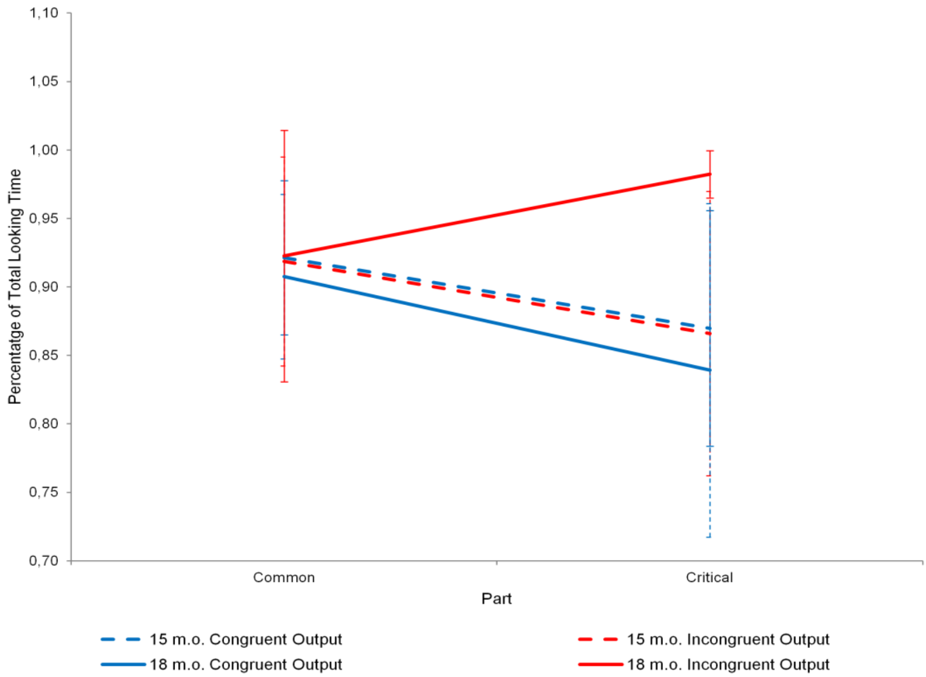

Fig 2. Total Looking Time to Screen at the conflict context on the test phase across the two main parts. Error bars represents the 95% confidence interval.

DISCUSSION

The results of this research show that 18-months-old, but not 15-months-old infants represent the conflicts between two agents and make inferences about who is most likely to win when there are no visible cues of physical dominance. When the low-ranked agent won during the test phase, 18-months-old infants increased their visual attention, looking longer to the screen, while 15-months-old infants showed the reverse pattern, a decrease of attention. Eighteen-months-old infants represented the social status of the different agents as stable across the different tasks and they expected the high-ranked agent to always prevail over the low-ranked agent. In our research only the social power in a resource allocation task was presented with no evidence of why one of the agents succeeded. In contrast with Mascaro and Csibra (2012) 15-mont-olds were not able to succeed in the task. We hypothesize that the more abstract nature of agents' hierarchical relationship may have hindered infants' understanding of the hierarchical situation. We propose that in our study infants had to link agents' social power with agents' social status to predict the outcome in the test phase.

Social status and social power are two main concepts of hierarchical relationships that differ in their conceptualization. Social status is the rank that someone has in a group based on the comparison of one agent to the others and it is reflected in the way agents interact with each other. Social power is the capacity of one agent to access and control specific limited resources (Magee & Galinsky, 2008). The relationship between both concepts is asymmetrical. An individual with a high power over one resource does not have a high status if that resource is not well valued by the other agents. In addition, controlling one resource does not involve controlling others. By contrast, holding a high status in a group consistently entails a high social power: the higher the social status of one individual, the more resources she will control in general. Therefore, in this conceptualization, social power is domain-specific while social status extends across different domains (Fragale et al., 2011). In our study, we familiarized infants with agents' social power over a specific and valued resource, the teddy bear. To be able to predict the outcome in the test phase with a new type of resource, infants had to generalize agents' social power observed in the familiarization phase to the new situation presented in the test phase (sitting in an armchair). Such generalization required the representation of agents' social status, not directly observable in the experiment. Only by assuming that the agent's social power over one resource came from her social status, infants could predict her social power over other non-related resources. Such computation would make it difficult for the younger infants to predict who was going to prevail in the test situation.

The presentation of agents' social power without signals of physical imposition could induce the interpretation of their hierarchical relationship as part of an agreement between the agents. Humans' social hierarchies can arise by two reasons, by dominance or by prestige (Cheng, Tracy, Foulsham, Kingstone, & Henrich, 2013a; Gil-White & Henrich, 2001). Dominant-subordinate relationships emerge when some agents impose their will over other agents, for instance by using their physical attributes. However, prestige relationships arise from the exchange of benefits between the agents. Some agents because of their knowledge or expertise in specific domains are highly valuable for the group. For instance, in contrast to most social animals; humans learn from and are leaded by the most competent agents regardless of their physical features (Chudek, Heller, Birch, & Henrich, 2012; Smith et al., 2016b). In return of those benefits, group members give to those high competent agents a higher status by showing them respect and allowing them to get more resources (social power)(Price & Van Vugt, 2014). Although we cannot determine what type of relationship infants attributed to the agents in our experiment, our results leave the door open to the possibility that they reflected agents' social prestige. Hence, the three month delay might be due the need to understand second-order benefits, where success does not depend on being the bigger or strongest agent but it depends on other characteristics that in a long term benefit all agents.

Understanding how infants interpret different types of social hierarchies is at present largely unknown. Most studies on how social hierarchies modulate cognitive processing in infants use paradigms involving physical dominant-subordinate relationships when establishing the social rank of the agents (Castelain, Bernard, Van der Henst, & Mercier, 2016; Thomas, Abramyan, Lukowski, Thomsen, & Sarnecka, n.d.). However, to be aggressive or the one who explicitly takes something from others may be perceived as morally wrong. This makes difficult to attribute results to the understanding of social hierarchies, as there may be a confound between the notion of “high rank” agent and “bad” agent (Geraci & Surian, 2011; Schmidt, Sommerville, Chalub, Chapman, & Passos-Ferreira, 2011; Sloane, Baillargeon, & Premack, 2012).

The relevance of the present investigation lies on the fact that the most common situation in humans' daily life is that people recognize others’ social status based on their social interactions not by the physical superiority of one agent over others. Here we present the first results showing that as early as 18 months of age infants are able to infer social status by observing interactions not involving physical dominance. Our research does not inform about the type of hierarchical relations infants represented, either based on agents’ dominance or their prestige, an important research question that future research will have to address.

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AUTHOR CONTRIBUTIONS

Jesus Bas and Nuria Sebastian-Galles developed the study concept and designed the experiments. Testing, data collection and statistical analysis were performed by J. Bas. J. Bas and N. Sebastian-Galles interpreted the results and wrote the manuscript. All authors approved the final version of the manuscript for submission.

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b. Infants' representation of leader-follower relations

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ABSTRACT

Leader-follower relations, which regulate who organizes collective actions when the goals of the members of a group are aligned, are central in many social species. Here we tested whether infants represent leader-followers relations, and whether they expect them to be asymmetric and stable across contexts. Twelve-, fifteen- and eighteen-month-old infants were familiarized to two agents (the followers) selectively imitating the actions of another agent (the leader). During test, the infants observed either a follower failing to follow the leader's path (incongruent outcome), or the leader failing to follow a follower's path (neutral outcome). The participants looked significantly longer at the incongruent than at the neutral outcome, thus demonstrating a capacity to represent a leader-follower relation and providing evidence for an early representation of the hierarchical social relations that regulate collective actions.

INTRODUCTION

Leader-Follower relations are common across social contexts, cultures, and species. Members of social groups face recurrent problems, such as collective movement, finding and allocating resources, within-group conflicts, and between-group interactions (Smith et al., 2016), which require multiple individuals to coordinate efficiently. In many of these cases, certain individuals act as leaders; they have more influence than others on the collective activities of the group. It has been argued that following a single (or a few) leader(s) is one way to simplify the problem of coordinating collective behaviors (Dyer, Johansson, Helbing, Couzin, & Krause, 2009; Price & Van Vugt, 2014).

The aim of the present study was to explore human infants' capacity to recognize leader-follower relationships and to track such relationships across contexts. We defined "leaders" as individuals who have a non-random differential influence on the behavior of their group (Smith et al., 2015). Leaders influence the types of behavior a group engages in, and also how the group coordinates collective actions. The leader's role contrasts with that of the "followers," whose behavior is usually influenced by the leaders. This definition of leaders applies to individuals who set complex goals and action plans, e.g., a manager who assigns tasks to employees in a firm. However, this definition also applies to individuals who are simply followed, or copied by others, e.g., an individual that begins to move towards a food source, or to depart on a migration route, and is then followed by the members of an entire group (Boinski & Garber, 2000; Couzin, Krause, Franks, & Levin, 2005).

Most studies investigating the early ontogeny of representations of hierarchical social relations have focused on social dominance, i.e., a relation that determines who prevails when agents have conflicting goals (Hand, 1986). In a seminal study, Thomsen et al. (2011) demonstrated that, from 10 months of age, human infants expect physically larger agents to predominate over smaller ones when two agents collide with each other. Using a similar scenario, Pun et al. (2016) showed that when two agents collide with each other, 6-month-olds expect individuals from numerically larger groups to prevail. Mascaro and Csibra (2012) found that infants expect social dominance to be a stable social relationship across contexts. After observing a first agent prevail over a second agent in one context, 15-month-olds expected the first agent to prevail again in a different context in which no physical conflict was involved. Before their second birthday, infants combine representations of social dominance relationships into hierarchies (Gazes, Hampton, & Lourenco, 2017; Mascaro & Csibra, 2014). Young children's representation of social dominance influences their expectations and decisions regarding resource distribution (Charafeddine et al., 2015; Enright, Gweon, & Sommerville, 2017), and about whom to learn from (Bernard et al., 2016; Castelain, Bernard, Van der Henst, & Mercier, 2016). Altogether, previous studies have revealed that the ability to represent hierarchical relations develops early, and could be a component of the core system that underpins humans' conception of the social world (Liberman, Woodward, & Kinzler, 2017; Pun et al., 2016). Crucially, all the above-mentioned studies focused on the representation of social dominance, and on situations in which individuals' goals were in conflict.

In contrast to dominance relations, leader-follower relations contribute to organizing individuals' interactions when the goals and interests of the group members are aligned. In a social environment where leaders coordinate the activities of the group members, representing leader-follower relations is crucial for predicting and interpreting social behaviors. Representations of leadership are also fundamental for acting strategically in many social contexts: for example, choosing leaders, forming relationships with leaders, or deciding to act as a leader. Perhaps surprisingly, evidence regarding the early development of the conceptual building blocks of representations of leadership is scarce. However, by preschool age, children have been shown to be able to tell that an individual who is benevolent and whose orders are followed by others is "in charge" (Gulgoz & Gelman, 2016). Furthermore, after watching an individual imitate another, five-year-olds tend to assume that the imitated individual is the "boss" (Over & Carpenter, 2015). The precocious emergence of these explicit representations of social status suggests that more implicit representations of leadership may develop even earlier (Kitano & Tafoya, 1983; Shin, Recchia, Lee, Lee, & Mullarkey, 2004).

To investigate the ontogeny of representations of enduring leader-follower relations, we exposed infants to animated events, in which the influence that two different agents had on other agents' behavior was systematically varied. We chose to probe infants' understanding of direct behavioral manifestation of leader-follower relations, for two reasons. First, many cues, such as posture, height, size, clothing, ways of speaking, and social categories can be exploited to infer social power (Brey & Shutts, 2015;

Charafeddine et al., 2015; Gulgoz & Gelman, 2016). Yet, direct behavioral manifestations of leader-follower relations are the benchmark against which the reliability and relevance of all others cues of leadership can be assessed. Second, leadership can have various sources. It can be established by intimidation, by persuasion, by trading benefits, or it can be based upon the attribution of positive personal characteristics to the leader (Cartwright, 1965; Dahl, 2007; Gil-White & Henrich, 2001; Tooby & Cosmides, 1996). Because in the present study we were not interested in infants' capacity rely on, or infer, these arguably complex sources of leadership, we provided the participants with direct evidence regarding the influence that a leader exerted on the actions performed by the other members of the group. We induced the attribution of leadership by showing the infants that a group copied the actions of a particular individual, and then probed their expectations regarding the stability of leader-follower relations in a path-following setting. We used the reproduction of movements and path-following to convey leadership because infants are sensitive to these cues from their first year of life (Powell & Spelke, 2013; Powell & Spelke, 2018; Pulverman, Golinkoff, Hirsh-Pasek, & Buresh, 2008; Pulverman, Song, Hirsh-Pasek, Pruden, & Golinkoff, 2013).

Using an eye tracker, we recorded 12-, 15-, and 18-month-olds infants' gaze behavior while they watched short animations depicting the behaviors of four agents (see Figure 1). During the familiarization phase, two agents (the followers) consistently copied the action performed by a third agent (the leader) and ignored the action performed by a fourth agent (the non-leader). During the test phase, we measured infants' expectations in a novel context, in which one agent had to choose a path to follow. In the “Incongruent” test event, a follower followed the path of the non-leader instead of the path of the leader. In the “Neutral” test event, the leader followed the path of the non-leader instead of the path of a follower. If infants expect followers to follow the leader (but not vice versa), they should look longer at the Incongruent event than at the Neutral event. Contrasting an Incongruent event with a Neutral one, and not with a Congruent one (in which the follower would follow the leader), has several advantages. First, it emphasizes the asymmetry of the leader-follower relation: followers are influenced by leaders, but leaders should not be necessarily influenced by followers. Second, such contrast avoids interpretations in terms of affiliation. Powell and Spelke (2013) showed that infants expect that individuals acting alike belong the same group. A congruent-incongruent contrast could be confused as an affiliation test; the agents who acted alike end up or not together. With a neutral-incongruent contrast the agents who acted alike never end up together. Third, both test events finish in the same way: one agent (the leader or the follower) imitating the path of the non-leader. Thus, our study was designed to simultaneously probe infants’ expectations about the stability and about the asymmetry of a leader-follower relationship avoiding other interpretations.

METHODS

The study reported in this paper was conducted according to the principles expressed in the Declaration of Helsinki and approved by the local ethical committee (The Clinical Research Ethical Committee of the Parc de Salut Mar, Barcelona). All parents signed an informed consent for their infants to participate in this study.

Participants

Forty-eight infants were included in the analysis, of whom 16 were 12 months old (*M* = 368, *SD* = 13 days), 16 were 15 months old (*M* = 473, *SD* = 10 days), and 16 were 18 months old (*M* = 564, *SD* = 8 days). The sample sizes were set to match those in previous comparable studies (Mascaro & Csibra, 2012; Thomsen et al., 2011)**.** Seventy-four additional infants were tested but excluded from the final analysis because they did not complete the experiment (23); because they did not look at the screen when the measurement of looking time started (37) (this distribution was equivalent across the three ages we tested (see SI Table S1)); because of parental interference (4); because of experimental error (9); or because they looked at the screen for the maximum amount of time during both test trials (1).The participants were recruited by visiting maternity rooms at the Hospital Quirón and the Clínica Sagrada Família in Barcelona, Spain. All participants were healthy, full-term infants (more than 37 weeks of gestation).

Stimuli

The stimuli were 120-second-long computer-based animations involving four different “agents” represented by abstract geometric figures, each with a pair of eyes. At the start of all videos, the agents entered the screen. Two agents positioned themselves along the central vertical axis (one at the top and the other at the bottom of the screen) and two agents positioned themselves along the central horizontal axis (one on the left side, and the other on the right side of the screen).

The familiarization phase consisted of four repetitions of a sequence of events, in which the agents (i) exchanged positions and (ii) demonstrated their respective roles ("leader", "non-leader", and "followers") (see Movie S1 and Figure 1). To exchange positions, the agents gathered in the central area of the screen (1 s), they revolved 180° clockwise around the center following a semi-circular path (2 s), and they spread out by moving away from the center of the screen (1 s). Thus, the agent who was initially at the top of the screen swapped position with the agent who was initially at the bottom of the screen, and the agent who was initially on the left side of the screen swapped position with the agent who was initially on the right side of the screen. This exchange of positions served to counterbalance the agents' locations. After the agents exchanged positions, the leader and the non-leader performed short intransitive actions simultaneously, each in a different manner (e.g., one moved up and down while rotating, the other moved horizontally from side to side). These actions lasted for 2 s, and were repeated twice with a pause of 0.5 s in between. After a delay of 1 s, the other two agents (the followers) performed the same actions as the leader. Thus, the infants observed the followers imitate the actions of the leader 4 times, while the non-leader was never imitated.

The test phase followed the familiarization phase without interruption. One follower left the scene by moving out of the borders of the screen. The remaining follower, the leader, and the non-leader positioned themselves at the top central part of the screen. In the Incongruent movies, the follower positioned itself above the leader and the non-leader, at equidistance from them. Then, the leader and the non-leader slid down along parallel zigzag paths (1 s), before "calling" the follower by emitting a sound while rocking gently from left to right (0.5 s). The follower then moved towards the leader and the non-leader (1 s). This sequence (leader and non-leader moving downwards before being followed by the follower) was repeated four times as follows: the agents slid down diagonally twice in the left direction, and twice in the right direction. At the end of this sequence, the agents ended up in the central area of the screen. In the crucial part of the test phase, the leader and the non-leader moved in opposite directions (one towards the bottom left corner of the screen, and the other towards the bottom right corner of the screen). Then, the leader and the non-leader "called" the follower by emitting a sound while rocking gently from left to right (0.5 s). The follower then slid down along the central vertical axis (1 s), paused (0.5 s). Subsequently, the follower followed the path of the non-leader (2 s, Incongruent test event). Once the follower was close to the non-leader, the video froze until the infants looked away from the screen for 1.5 s, or after 30 s elapsed from the beginning of the Incongruent test event. The Neutral movies (see Movie S2) were identical to the Incongruent movies, except that during the test phase, it was the leader who followed the other two agents as they moved down the screen. At the end of the Neutral movies, the leader followed the path of the non-leader rather than the path of the follower (Neutral test event). To be included in the data analysis, the infants had to look without interruption at the screen while the Incongruent and the Neutral test events occurred without interruption.

Two sets of agents and actions were used in these events. Set 1 agents included a red triangle, a blue rounded blob, a purple hexagon, and a yellow octagonal star, paired with the following two familiarization actions: moving up and down while rotating, and moving horizontally from side to side. Set 2 agents included an orange pentagon, a brown circle, a blue square and a pink trapezoid, paired with the following two familiarization actions: drawing a "V" shape, and repeatedly expanding and contracting (see Movie S3 as an example).

Procedure

The infants were presented with a sequence of familiarization and a test event involving one set of agents and action, followed by another sequence of familiarization and a test event involving the other set of agents and actions. The test events followed the familiarization events without interruption, and one of the test events was Neutral while the other test event was Incongruent for each infant.

Several factors of the stimuli were counterbalanced within or across participants. Half of the infants observed first with the sequence ending with the Neutral test, and the other half of the infants observed first the sequence ending with the Incongruent test. During the familiarization phase, the agents performed the two different intransitive actions four times. Across these repetitions, the actions of the agents were varied using an ABBA pattern for the leader and the followers, and a BAAB pattern for the non-leader, where A and B refer to two different intransitive actions. Thus, in each familiarization sequence, the leader and the non-leader performed the same two actions at the same two locations, but at different times. The set of shapes and actions that was used for the Incongruent or for the Neutral sequence was counterbalanced across participants. Furthermore, for each set of agents, the particular shapes associated with the roles of the leader, the non-leader and the followers were counterbalanced across participants.

The agents' positions during the test phase were also counterbalanced so that at the end of the video the non-leader was positioned on the right side of the screen for half of the participants and on the left side of the screen for the other half of the participants. The positions of the other agents varied accordingly.

The whole experiment lasted approximately 4 minutes.

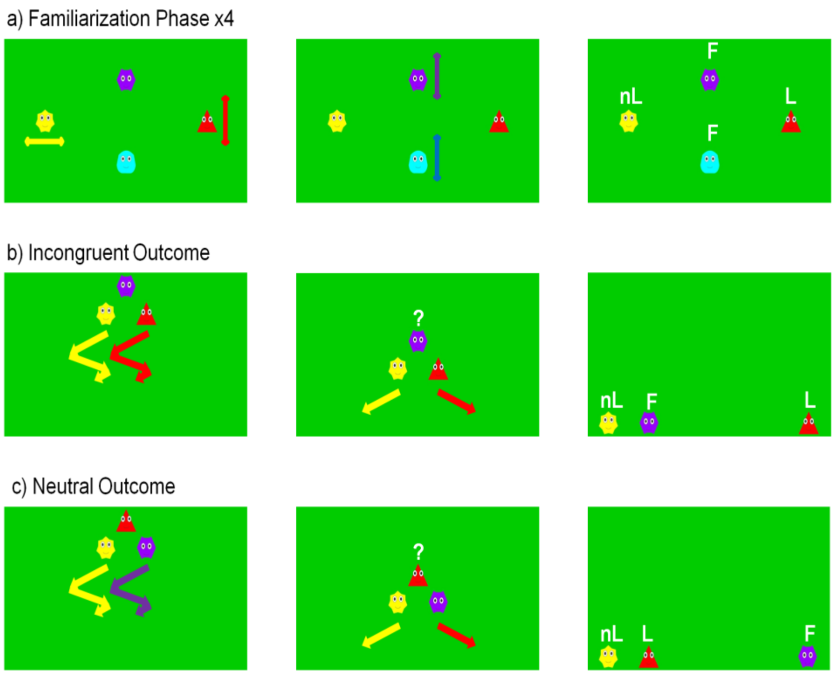

Figure 1. Experimental stimuli. a) During the familiarization phase, two agents, the leader (L) and the non-leader (nL) performed two different actions; next, two other agents, the followers (F), copied the action performed by the Leader. b) During the Incongruent test, a follower followed the leader and the non-leader, until the leader and non-leader took different paths. The follower then followed the path of the non-leader. c) During the Neutral test, the leader followed a follower and the non-leader, until the follower and non-leader took different paths. The leader then followed the path of the non-leader.

Apparatus

The participants were tested in a sound-attenuated room at the "Laboratori de Recerca en Infància" (Center for Brain and Cognition, Universitat Pompeu Fabra, Barcelona). The infants sat on their caregiver's lap at approximately 65 cm from a 23" screen (resolution 1920 x 1080 pixels) on which the stimuli were presented. After a five-point reference calibration, a Tobii® TX300 eye tracker recorded the gaze of the infants during the experiment. In addition, the participants' behavior during the session was recorded using a Sony HDR-HC9E camera (temporal resolution: 25 frames/s). The presentation of the stimuli was controlled using the Psychtoolbox-3 toolbox in MATLAB®.

Coding and analysis

Video recordings

The video recordings were coded offline by analyzing frame by frame whether the infants looked at the screen or looked away. For each test trial, the looking times were measured from the beginning of the final movement of the follower (Incongruent test event) or the leader (Neutral test events), i.e., from when they departed on the path of the non-leader. The looking times were measured until the infant looked away for more than 1.5 s or after 30 s elapsed. Originally, the planned look-away criterion for stopping the test movie was set at 2 s, to match comparable studies (Mascaro & Csibra, 2012; Thomsen et al., 2011). However, the experimenter mistakenly interrupted the test movie at 1.5 s in the first group of infants tested (18-month-olds). Consequently, the look-away criterion had to be reduced to 1.5 s. To maintain the protocol consistent, the look-away criterion was then adjusted to this value for the additional age groups (15 and 12 months-old) that were tested subsequently. Blinks were considered as looking away if they lasted for more than 0.2 s. Infants who looked at the screen for the maximum amount of time during both test trials were excluded. All recordings were coded by a primary coder, who was unaware of the hypotheses of the study, and the first author. A high inter-coder agreement was achieved (ICC = .992). We used the data from the primary coder to perform our analyses. Shapiro-Wilk's tests revealed that the looking times departed from normal distribution in both the Neutral (W = 0.899, p = .001) and the Incongruent test event (W = 0.858, p < .001). To better approximate normal distribution, we log-transformed the raw data before performing parametric statistics (Csibra, Hernik, Mascaro, Tatone, & Lengyel, 2016). The means of the raw and log-transformed data can be found in Tables S2 and S3 in the SI (the data for all individual participants are shown in Tables S4 and S5 in the SI). For ease of reading, the untransformed raw data are depicted in Figure 2. For the effects of main interest, we also report non-parametric statistics. All the statistical tests were two-tailed.

Eye-tracking data

We used eye-tracking data to conduct two kinds of exploratory analyses. First, during the familiarization phase, we measured the total looking time to the different agents while the leader and the non-leader performed their actions. We then divided the looking time to each particular agent by the looking time to the whole screen over the same period. We computed this ratio for each repetition of the actions in each of the two familiarization movies and converted it in percentages.

A second exploratory analysis assessed the infants' first fixation during the test phase, while the centrally located agent paused for 0.5 s right before performing its final movement (following the path of the non-leader). Over this time period we measured the first fixation (> 250 ms) the infants made towards one of the two 17 cm x 9,6 cm Areas of Interest surrounding the two agents located at the bottom of the screen.

Data availability

The looking times coded from video recordings and the eye-tracking datasets of the current study are available in the Supplementary Information. The raw eye-tracker data are available to all interested researchers upon request.

RESULTS

The looking times are depicted in Figure 2. We performed a mixed model ANOVA of total looking time at the screen with Age (12- , 15-, or 18-months) and order of the test events (Neutral outcome first vs Incongruent outcome first) as between-participants factors, and Congruency (Incongruent vs. Neutral outcome) as a within-subjects factor. The ANOVA yielded only a main effect of Congruency ($F(1,42) = 17.52$, $p < .001$, $\eta^2_p = .294$). Separate analyses of each age group revealed that older infants looked significantly longer at the Incongruent test events than at the Neutral test events (15-month-olds: $t(15) = 3.30$, $p = .005$, $d = 1.76$; Wilcoxon's $Z = 2.43$, $p = .015$; 18-month-olds: $t(15) = 2.58$, $p = .021$, $d = 1.38$; Wilcoxon's $Z = 2.48$, $p = .013$). The effect of Congruency did not reach significance among the 12-month-olds ($t(15) = 1.74$, $p = .103$, $d = 0.93$; Wilcoxon's $Z = 1.50$, $p=.134$). The exploratory analyses of the eye-tracking data did not yield any easily interpretable pattern of results (the data can be found in SI Table S6 and S7).

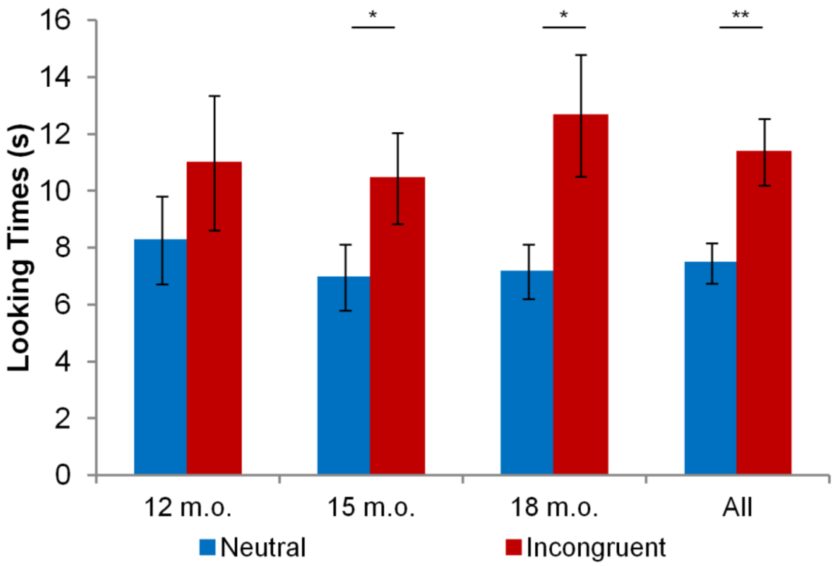

Figure 2. Infants' looking times at the screen, in seconds, as a function of age group and test events (bars represent the standard errors). Infants at 15 and 18, but not 12, months looked significantly longer at the Incongruent event than at the Neutral event. All ages collapsed yielded the same results.

DISCUSSION

Previous studies have shown that infants represent social dominance, a social relation extracted from the observation of events in which agents have conflicting goals. Here, we found that human infants also interpreted social interactions in terms of leader-follower relations. Our results demonstrated that infants aged from 12 to 18 months expected agents who imitated the leader in one context to follow the leader's path in a different context. However, the participants did not expect the leader to follow its followers (or anyone else). Therefore, infants possess the capacity to represent leader-follower relationships from a third-party viewpoint from a very early age. Furthermore, our results indicate that, from their second year of life, infants can identify leaders and followers by simply observing their behaviors, which could allow them to obtain information regarding the cues that are correlated with leadership status, including potential culture-specific attributes.

The infants demonstrated expectation of four key properties of leadership in this study. First, they expected the leader-follower relations to display stability over time. The participants expected the agents who had imitated the movement of a leader in one context to follow the path of the leader in a second, different context. Whether infants would expect leadership to generalize across more different situations and domains is an important question for future research. Given that leadership status is often based on expertise, it is plausible to assume that infants would not expect leadership to generalize to entirely dissimilar domains.

Second, the infants expected the leader-follower relations to be asymmetric: they looked longer at a follower who did not follow the leader, than at the leader who did not follow a follower. Therefore, the infants did not simply assume that the leader and the followers were affiliated, and thus imitated one another (Powell & Spelke, 2018). In contrast, the infants recognized that one agent was more likely to influence the other agents' actions and inferred the asymmetric relation between the agents without further evidence. Infants' capacity to identify the source of social information accepted by the majority of group members is not only important for recognizing leaders but may also help infants determine from whom to learn (Gil-White & Henrich, 2001).

Third, the infants expected the followers to be influenced by the leaders in the absence of identifiable coercion, threat, or tangible rewards. In our experiment, there was no evidence that the followers would (i) incur a cost for not following the leader, or (ii) receive immediate benefits from following the leader. Leadership can be achieved through coercion, or by trading resources for influence. However, many authors have argued that leadership is also often freely conferred, such that followers willingly select their leaders because of their positive qualities — such as competence or benevolence(Price & Van Vugt, 2014).

Fourth, the infants formed expectations for the leader-follower relations in the absence of identifiable conflict between goals. Thus, infants in the second year of life can represent both asymmetric hierarchical relations regulating conflict (i.e., social dominance) and asymmetric hierarchical relations regulating collective actions (i.e., leadership). How the representations of these two types of hierarchical relations interact is an important question for future investigations. Similarly, whether infants assume that leaders are likely to receive material and/or social benefits from followers can be tested in future studies.

Here, we tested infants' understanding of leadership "by example", i.e., using situations in which the actions or goals of a leader are reproduced by other members of a group (Cartwright, Gillet, & Van Vugt, 2013; Clemson & Evans, 2012). Our results confirm that infants can infer leader-follower relations based on their capacity to recognize that certain agents copy another agent's behaviors.

However, this type of leadership is arguably one of the simplest, and probably that is why it is widespread across many animal species (Couzin et al., 2005; Dyer et al., 2009; Guttal, Couzin, Couzin, & Simon Levin, 2010). Whether infants also have expectations about more complex forms of leadership —that involve giving orders or assigning roles in collective actions— is an important question for future studies.

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AUTHOR CONTRIBUTIONS

Jesus Bas, Olivier Mascaro and Gergely Csibra developed the study concept and designed the experiments. The testing, data collection and statistical analysis were performed by J. Bas. J. Bas, O. Mascaro, G. Csibra and N. Sebastian-Galles interpreted the results. J. Bas and O. Mascaro wrote the manuscript and G. Csibra and N. Sebastian-Galles critically reviewed it. All authors approved the final version of the manuscript for submission.

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Infants' representation of leader-follower relations (Supplementary Information)

Table S1. Number of infants who were excluded because they were not looking at the screen when looking time started to be measured

Group Age	First test outcome	Second Test Outcome	Both test outcomes	Total
12 m.o.	7	5	0	12
15 m.o.	6	6	2	14
18 m.o.	2	8	1	11

Table S2. Means and CI of the base-10 log-transformed data

	First Author		**Primary Coder**	
	Neutral	**Incongruent**	**Neutral**	**Incongruent**
12 m.o.	0.785 [0.590; 0.980]	0.912 [0.725; 1.098]	0.794 [0.606; 0.982]	0.907 [0.719; 1.095]
15 m.o.	0.751 [0.597; 0.905]	0.941 [0.794; 1.089]	0.757 0.604; 0.909]	0.942 [0.795; 1.089]
18 m.o.	0.781 [0.641; 0.922]	0.992 [0.832; 1.153]	0.789 [0.651; 0.927]	1.002 [0.836; 1.169]
All	0.772 [0.684; 0.860]	0.948 [0.860; 1.037]	0.780 [0.694; 0.866]	0.950 [0.860; 1.041]

Table S3. Means and CI of the raw data in seconds

	First Author		**Primary Coder**	
	Neutral	**Incongruent**	**Neutral**	**Incongruent**
12 m.o.	8.208 [4.913; 11.502]	11.021 [6.006; 16.036]	8.259 [4.985; 11.532]	10.977 [5.945; 16.009]
15 m.o.	6.876 [4.411; 9.340]	10.431 [7.022; 13.839]	6.947 [4.483; 9.411]	10.436 [7.030; 13.842]
18 m.o.	7.070 [5.007; 9.134]	12.1 [8.008; 16.191]	7.155 [5.100; 9.209]	12.638 [8.078; 17.198]
All	7.385 [5.957; 8.812]	11.184 [8.923; 13.445]	7.453 [6.032; 8.875]	11.350 [8.995; 13.705]

Table S4. Raw data in seconds of all the participants

	First Author		Primary Coder	
Group Age	Neutral	Incongruent	Neutral	Incongruent
12 m.o.	1,480	9,580	1,621	9,586
	10,830	10,030	10,830	10,070
	2,480	7,820	2,480	7,820
	13,580	8,240	13,410	8,240
	9,580	14,690	9,620	14,680
	9,030	9,240	9,030	9,240
	4,060	4,550	4,103	4,550
	2,930	1,970	2,930	1,970
	1,580	4,240	1,930	3,620
	5,550	5,930	5,552	5,930

	11,930	18,000	11,930	18,000
	9,000	9,550	9,480	9,414
	6,890	5,060	6,820	5,069
	2,790	2,240	2,790	2,240
	24,620	32,620	24,620	32,620
	15,000	32,590	15,000	32,590
15 m.o.	6,760	27,000	6,930	27,000
	8,380	5,240	8,410	5,240
	14,900	19,830	15,070	19,830
	1,620	2,070	1,690	2,070
	4,590	7,140	4,720	7,140
	2,100	3,720	2,100	3,720
	19,210	13,760	19,210	13,760
	8,240	14,760	8,210	14,720
	4,970	6,480	5,340	6,380
	5,830	8,720	5,830	8,690
	4,000	7,340	4,000	7,590
	5,620	7,310	5,720	7,310
	5,000	7,760	5,030	7,760
	9,140	14,970	9,140	14,970
	7,380	9,210	7,480	9,210
	2,280	11,590	2,280	11,590
18 m.o.	11,440	14,000	11,552	14,000
	14,380	16,720	14,440	16,724

	14,340	23,310	14,480	23,410
	3,000	8,680	3,000	8,580
	5,200	17,410	5,310	17,370
	7,820	8,240	7,820	8,370
	3,310	3,310	4,060	3,310
	3,750	4,860	3,750	4,860
	1,510	7,440	1,510	7,340
	5,580	11,370	5,620	11,414
	6,340	8,510	6,448	8,510
	9,100	3,060	8,960	3,100
	7,510	4,240	7,580	4,310
	4,860	20,730	4,860	29,200
	9,790	29,310	9,890	29,310
	5,200	12,410	5,200	12,410

Table S5. Base-10 log-transformed data of all the participants

	First Author		Primary Coder	
Group Age	Neutral	Incongruent	Neutral	Incongruent
12 m.o.	0,170	0,981	0,210	0,982
	1,035	1,001	1,035	1,003
	0,394	0,893	0,394	0,893
	1,133	0,916	1,127	0,916
	0,981	1,167	0,983	1,167
	0,956	0,966	0,956	0,966
	0,609	0,658	0,613	0,658

	0,467	0,294	0,467	0,294
	0,199	0,627	0,286	0,559
	0,744	0,773	0,744	0,773
	1,077	1,255	1,077	1,255
	0,954	0,980	0,977	0,974
	0,838	0,704	0,834	0,705
	0,446	0,350	0,446	0,350
	1,391	1,513	1,391	1,513
	1,176	1,513	1,176	1,513
15 m.o.	0,830	1,431	0,841	1,431
	0,923	0,719	0,925	0,719
	1,173	1,297	1,178	1,297
	0,210	0,316	0,228	0,316
	0,662	0,854	0,674	0,854
	0,322	0,571	0,322	0,571
	1,284	1,139	1,284	1,139
	0,916	1,169	0,914	1,168
	0,696	0,812	0,728	0,805
	0,766	0,941	0,766	0,939
	0,602	0,866	0,602	0,880
	0,750	0,864	0,757	0,864
	0,699	0,890	0,702	0,890
	0,961	1,175	0,961	1,175
	0,868	0,964	0,874	0,964

	0,358	1,064	0,358	1,064
18 m.o.	1,058	1,146	1,063	1,146
	1,158	1,223	1,160	1,223
	1,157	1,368	1,161	1,369
	0,477	0,939	0,477	0,933
	0,716	1,241	0,725	1,240
	0,893	0,916	0,893	0,923
	0,520	0,520	0,609	0,520
	0,574	0,687	0,574	0,687
	0,179	0,872	0,179	0,866
	0,747	1,056	0,750	1,057
	0,802	0,930	0,809	0,930
	0,959	0,486	0,952	0,491
	0,876	0,627	0,880	0,634
	0,687	1,317	0,687	1,465
	0,991	1,467	0,995	1,467
	0,716	1,094	0,716	1,094

Table S6. Percentage of total looking time to each agent during the actions of the leader and non-leader in the familiarization phase.

	non-Leader	**Leader**	**Followers**
	52,4	25,3	22,3
	42,3	29,1	28,3
	50,6	49,1	0
	29,3	41,2	29,4

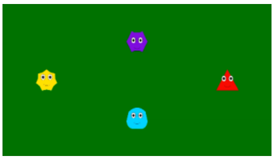
12 m.o.	49	20,1	26,3
	35,4	13,3	49,5
	12	59	12,3
	39,7	22,8	37,3
	44,8	22,1	32,8
	65,6	16,9	17
	24,9	32,8	42,1
	50,2	31,2	18,5
	62,4	18,2	9,7
	31,6	41,2	25,4
15 m.o.	52,2	28,2	19,6
	33,6	34,3	29
	35,4	48,2	16,3
	36,9	38,7	12,9
	35,4	37,7	26,6
	33	32,2	33,1
	35,4	51,3	11,7
	41,5	24,7	33,7
	23,9	72,9	3,1
	28,1	48,8	23
	55,2	28,7	13,5
	42,8	46,9	8,2
	35	34,7	30,2
	38,8	24,6	36,5
	35,8	55,8	8,1

	58,3	28,2	13,5
	40	43,5	16,3
	34	5	0,9
	28,5	33,1	38,3
	30,1	37,4	31,5
	19,7	47,9	30
	34,5	34,7	18,7
	27	42,4	30,1
	29,3	62,5	7,6
	26,4	50,5	22,9
	27,7	40,6	30,3
	56,2	35,8	6,7
18 m.o.	43,3	39,4	16
	39,6	36,8	19,4
	43,2	43,5	12,6
	40,3	43,1	16,5

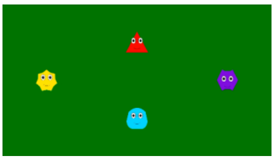
Table S7. Number of infants whose first fixation was directed towards one of the agents located at the bottom of the screen (non-leader, follower or leader) before the Neutral or the Incongruent Test Event. "Other" refers to infants who did not perform any fixation towards the agents located at the bottom of the screen.

	Neutral Test Event			Incongruent Test Event		
	Non-Leader	Follower	Other	Non-Leader	Leader	Other
12 m.o.	1	4	9	5	3	6
15 m.o.	4	6	6	7	4	5
18 m.o.	3	5	8	5	7	4

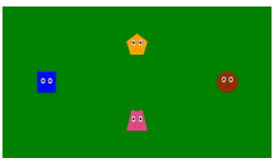
Movie S1. Incongruent Movie (Set 1). Familiarization and incongruent outcome.



Movie S2. Neutral Movie (Set 1). Familiarization and neutral outcome.



Movie S3. Incongruent Movie (Set 2). Familiarization and incongruent outcome.



c. Infants' representation of social hierarchies. From social power to leadership

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This article is currently in preparation

ABSTRACT

Previous studies have shown infants' capacity to represent hierarchical relations regulating conflict, as well as those regulating collective actions. The current study aims to explore infants' expectations about the relationship between both types of social hierarchies. We presented to 18-month-old infants short animations in which one agent observed other two agents successfully pick up a ball individually. However, when both agents wanted to pick the ball up at the same time, only one of them prevailed (always the same agent). Critically we manipulated how the winner prevailed, by showing or not physical dominance. Next, the observer followed one of the agents - either the "winner" or "loser" of the ball task. Results showed that infants expected agents with a high social power (the winner) to be the leader, but only when they did not use physical dominance to prevail. These results suggest that 18-month olds can represent different ways to succeed in conflict situations and they consider agents not using physical dominance to be the leaders.

INTRODUCTION

Social hierarchies are ubiquitous in social relationships and emerge naturally in social groups (Cummins, 2015; Halevy, Chou, & Galinsky, 2011). Recognizing group members' social status optimizes social interactions. A proper regulation of group's interactions leads to the welfare of its members, as well as the group as a whole (Dyer, Johansson, Helbing, Couzin, & Krause, 2009; Smith et al., 2016). As humans are immersed in social groups from birth, understanding infant's capacity to represent social hierarchies is a fundamental goal.

Many studies have addressed infants' capacity to represent hierarchical relations regulating conflict and social power (dominant-subordinate relationships). For instance, social hierarchies determine the allocation of limited and valued resources such as food, mates and territories. Using animated agents, Thomsen et a. (2011) showed that 10-month-old infants consider the size of an agent as an index of social status. In a scenario in which two agents' paths were in conflict, infants expected the physically bigger agent to prevail over the smaller one. Presenting a similar scenario Pun et al. 2016 showed that 6-month-olds expected individuals from numerically larger groups to prevail. Mascaro and Csibra (2012) presented to 15-months-old infants two agents competing to remain in a wall-delimited area. The agent who pushed stronger “won” the position inside the walls. Next, infants were presented with the same two agents competing to collect a resource. Infants expected the agent who prevailed in the first scenario to prevail in the second one. Bas and Sebastian-Galles (submitted) showed that when cues of physical dominance between the agents are not presented, it is not until 18 months of age that infants infer who prevails. Altogether, these studies provide compelling evidence of infants' capacity to represent agents' conflicting goals and infants' capacity to infer which agents are more likely to prevail.

In contrast, little is known about infants' capacity to represent hierarchical relations regulating collective actions (i.e. leader-follower relationships). Leader and follower roles emerge spontaneously in social interactions (King & Cowlishaw, 2009; Sahlins, 1963). When groups face coordination problems, such as group movement, some individuals may act as leaders: they influence more than others on groups' behavior (Boinski & Garber, 2000; Couzin, Krause, Franks, & Levin, 2005). Bas et al. (submitted) used animated agents to investigate infants' expectations about the stability of leader-follower roles in group movement contexts. These authors presented 12 to 18 month-old infants some agents, the *followers*, repeatedly imitating the movements of one agent, the *leader*, but not the movements of another agent, the *non-leader*. In the test phase, they tested infants' expectations about the stability of the leader-follower roles in a path-following setting. The leader and the non-leader moved together around the scenario while one of the followers followed them. Next, the leader and the non-leader separated, "forcing" the follower to choose who to follow. Bas et al. (submitted) contrasted this scenario with another where the leader was the agent who had to choose between following the leader or one of the followers. Results revealed that at 15 months of age, infants looked longer when a follower no longer followed a leader than when a leader did not follow a follower. These results indicate that infants represent leader-follower relationships as asymmetric and stable across time and situations, even when there is no evidence that followers receive external rewards (or punishment) for following (or not) the leader.

Dominant-subordinate and leader-follower relationships are two types of hierarchical relations that infants are able to represent. However, how the representations of these two types of relations interact remains unknown. Agents who prevail in conflict situations, as well as agents who significantly influence others' actions are identified as high-rank agents. We hypothesized that infants expect agents who prevail in conflict situations to be leaders. To test this hypothesis, we familiarized 18 to 20 months-old infants with a scenario where an animated agent*,* the *observer*, watched two agents (the *winner* and the *loser*) competing to obtain different resources. Both agents succeeded when trying to collect the resources separately; however, when they tried simultaneously to obtain the same resource, the winner always prevailed over the looser. Importantly, we manipulated the way the winner prevailed: either with external cues of physical dominance (by pushing the loser) or without them (no physical interaction between the agents). Next, in the test scenario, the winner and the loser were followed by the observer until they separated, and the observer had to "choose" who to follow. Infants' total looking time was measured in the two possible outcomes: the observer following the winner and the observer following the loser. .

When the winner prevailed with no physical interaction, infants could make two types of inferences. First, they might assume that in past interactions both agents conflicted and one of them prevailed by some kind of physical dominance. In the experimental situation, the loser already knew what could happen and avoided the conflict. If it was the case, both types of familiarization would lead to the same results during the test phase. Considering leader-follower relationships as byproducts of dominant-subordinate relationships, the observer would follow the winner in both cases. Second, infants might infer that the winner prevailed by other attributes not related with physical dominance such as its prestige. Some authors suggest that human leadership emerge from prestige-based hierarchies and not from dominant-subordinate ones. If both types of familiarization lead to the different results during the test phase, that would suggest that infants were representing two different types of social relationship between the conflicting agents (Price & Van Vugt, 2014; Vugt et al., 2007).

METHODS

The study reported in this paper was conducted according to the principles expressed in the Declaration of Helsinki and approved by the local ethical committee (The Clinical Research Ethical Committee of the Parc de Salut Mar, Barcelona). All parents signed an informed consent for their infants to participate in this study.

Participants

Thirty-two 18-to-20 months-old infants were included in the analysis (17 boys, M = 18, SD = 12 days), Sample sizes were set to match those of previous comparable studies (Bas, et al. submitted). Ten additional infants were tested but excluded from the final analysis because they did not finish the whole experiment (4); because of parental interference (3); because of experimental error (3).The participants were recruited by visiting maternity rooms at private hospitals: the Hospital Quirón and the Clínica Sagrada

Família in Barcelona, Spain. All participants were healthy, full-term infants (more than 37 weeks of gestation).

Stimuli

The stimuli were around 190-second-long computer-based animations involving three different “agents” represented by abstract geometric figures, each with a pair of eyes. All the videos started showing the same scenario; one agent, "the observer", on the top-center of the screen. Then, the observer rocked twice making a sound (2s). From this scenario, the following situations could be presented.

Presentation of social power with physical dominance

The presentation of social power without physical dominance was composed by three movies that were repeated three times in the same order.

High-rank action (a1 in figure 1): One agent, “the winner”, entered the scene from one of the sides and rocked making a sound (2.5 s). Next, a white ball appeared at the center of the screen paired with a sound (1.5 s). Then, the winner approached the ball (1,5 s), stopped (0,5 s), and grabbed the ball (1,5). Finally, the winner went back to its initial position (1,5 s), jumped twice (1,5 s) and left the scene (1,5 s).

Low-rank action (a2 in figure 1): Another agent, “the loser”, entered scene from the opposite side than the winner. Then, it performed the same sequence of actions as the winner but from its side.

Conflict context without physical dominance (a3 in figure 1): Both agents, the winner and the loser appeared from their corresponding sides and simultaneously rocked making a sound (2,5 s). Next, a white ball appeared in the center of the screen paired with a sound (1.5 s). Then, the both agents approached next to the ball (1,5 s), stopped (0,5 s), and rocked (1) before the winner grab the ball (1 s). Finally, both agents returned to their initial positions (1,5 s), the winner jumped twice, while the loser did not move (1,5 s), then both agents left the scene (1,5 s).

<u>Presentation of social power with physical dominance</u>

The presentation of social power with physical dominance was similar to the one described for the social power without physical power but changing the conflict context.

Conflict context without physical dominance (a3 in figure 1): Both agents, the winner and the loser appeared from their corresponding sides and simultaneously rocked making a sound (2,5 s). Next, a white ball appeared in the center of the screen paired with a sound (1.5 s). Then, both agents approached the ball (1,5 s), stopped (0,5 s), and the winner repeatedly push the loser (2 s) before grabbing the ball (1 s). Finally, both agents went back to their initial position (1,5 s), the winner jumped twice, while the loser did not move (1,5 s), then both agents left the scene (1,5 s).

<u>Leadership Test</u>

*Leadership test (*b1, b2 and b3 in figure 1): The winner and the loser appeared from their corresponding sides and simultaneously rocked making a sound (2,5 s). Next, both agents positioned themselves at the top central part of the screen, in front of the observer and rocked again (3 s). Then, the winner and the loser slid down following parallel zigzag paths (1 s), before “calling” the observer by emitting a sound while rocking gently from left to right (0.5 s). The observer then moved towards the winner and the loser (1 s). This sequence (winner and loser moving downwards before being followed by the observer) was repeated four times as follows: the agents slid down diagonally twice in the left direction, and twice in the right direction. At the end of this sequence, the agents ended up in the central area of the screen (b1 in figure 1). In the crucial part of the test phase, the winner and the loser moved in opposite directions (one towards the bottom left corner of the screen, and the other towards the bottom right corner of the screen). Both agents simultaneously “called” the observer by emitting a sound while rocking gently from left to right (0.5 s). The observer then slid down along the central vertical axis (1 s), paused (0.5 s) (b2 in figure 1) and followed either the winner (winner-leader outcome) or the loser (loser-leader outcome) (2s) (b3 in figure 1). Once the observer was close to one of the agents, the video froze until the infants looked away from the screen for 2 s, or after 60 s had elapsed from the video was frozen.

Procedure

Half of the infants observed the presentation of the social power without physical dominance and half of the infants observed the presentation of the social power with physical dominance. All the infants were presented with two Leadership tests, one with the winner-leader outcome and other with the loser-leader outcome.

The order of test outcomes and the side where each agent entered the scene was counterbalanced between participants.

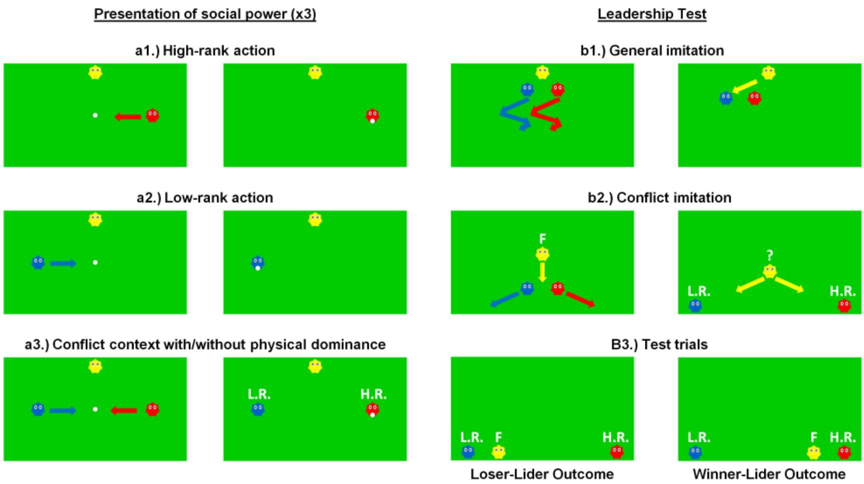

Figure 1. Experimental stimuli. a1) The high-rank agent grabs a ball; a2) The low-rank agent grabs a ball; a3) High-rank and Low-rank agents compete to grab a ball, high-rank agent prevails. b1)The observer follows the high-rank and the low-rank agent; b2) The high-rank and low-rank agents go away and the observer has to choose who to follow; b3) The observer follows either the high-rank or the low-rank agent.

Apparatus

Participants were tested in a sound-attenuated room at the "Laboratori de Recerca en Infància" (Center for Brain and Cognition, Universitat Pompeu Fabra, Barcelona). Infants sat on their caregiver's lap at approximately 65 cm from a 23" screen (resolution 1920 x 1080 pixels) on which the stimuli were presented. Participants' behavior during the session was recorded using a Sony HDR-HC9E camera (temporal resolution: 25 frames/s). The presentation of the stimuli was controlled using the Psychtoolbox-3 toolbox in MATLAB®.

Coding and analysis

Video recordings

During the leadership tests, the experimenter hold a button pressed whenever infants were looking at the screen and stopped pressing the button when the infants looked away. If infants were not looking at the screen during the pause before the last movement of the observer (c1 in figure 1), the video remained paused until 0.5s after infants looked back . If infants were looking at the screen before the pause, the pause lasted 0.5 s and the video continued. From this moment, infants' total looking time to the screen was measured until they looked away for more than 2 s or after 60 s elapsed. Total looking time was measured online and offline. For the online coding, MATLAB® calculated the amount of time the experimenter was holding the key when infants were looking the screen. For the offline codification an independent coder, who was naïve to the goals of the study, analyzed frame by frame if infants looked at the screen or looked away. Blinks were considered as looking away if they lasted for more than 0.2 s. Infants who looked at the screen for the maximum amount of time during both test trials were excluded. A high inter-coder agreement was achieved (ICC = .966). We used the data from the independent coder to perform our analyses. Shapiro-Wilk's tests revealed that the looking times departed from normal distribution in the winner-leader outcome after the presentation of social power without physical dominance ($W = 0.864$, $p = .022$) and after the presentation of social power with physical dominance ($W = 0.718$, $p < .001$). To better approximate normal distribution, we log-transformed the raw data before performing parametric statistics (Csibra, Hernik, Mascaro, Tatone, & Lengyel, 2016). The means of the raw and log-transformed data can be seen in Tables S1 in the SI (the data for all individual participants are shown in Tables S2 and S3 in the SI). To facilitating reading, the untransformed raw data are depicted in Figure 2. For the effects of main interest, we also report non-parametric statistics. All statistical tests were two-tailed.

Data availability

The looking times coded from video recordings datasets of the current study are available in the Supplementary Information.

RESULTS

The looking times are depicted in Figure 2. We performed a mixed model ANOVA of total looking time at the screen with type of presentation of social power (with physical dominance vs without physical dominance) and order of the test events (winner-leader outcome first vs loser-leader outcome first) as between-participants factors, and type of outcome (winner-leader vs. loser-leader) as a within-participants factor. The ANOVA yielded a triple interaction: type of social power presentation, order and type of outcome ($F(1,28) = 11.91$, $p < .002$, $\eta^2_p = .298$).

Separate analyses revealed that after the presentation of the social power without physical dominance scenario the total looking time was longer for the loser-leader than for the winner-leader ($t(15) = 2.894$, $p = .011$, $d = 1.06$; Wilcoxon's $Z = 2.172$, $p = .030$) but not after the presentation of the social power with physical dominance ($t(15) = .177$, $p = .862$, $d = 1.06$; Wilcoxon's $Z = .569$, $p = .569$).

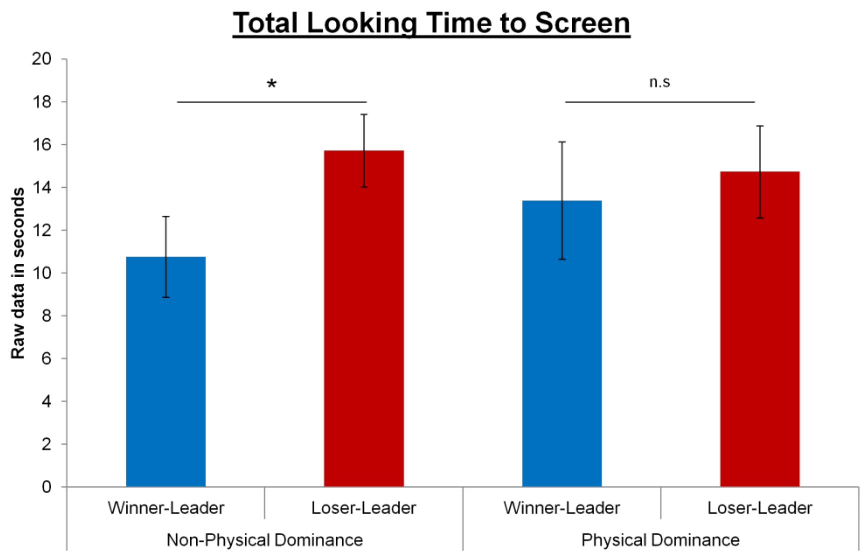

Figure 2. Infants' looking times at the screen, in seconds, as a function of type of social power presentation and output presented (bars represent standard errors). Infants looked significantly longer at the loser-leader outcome than at the winner-leader outcome after the presentation of the social power without physical dominance.

DISCUSSION

Two parallel research lines have shown that during the second year of life infants are able to represent different dimensions of social hierarchies. On the one hand, infants understand social hierarchies regulating conflicts. From 15 to 18 months, infants are able to represent agents' social power: the capacity to access and control valued resources (Mascaro & Csibra, 2012; Bas, J., et al. submitted). On the other hand, infants understand social hierarchies regulating collective actions. At 15 months of age, infants expect leaders, but not followers, influence other agents' behavior (Bas et al. submitted). Here we show that from 18 months of age, infants expect agents prevailing in a resource-allocation conflict to be the leaders in a path-following scenario. This expectation emerged only when the winner had shown no cue of physical dominance during the conflict. These results suggest that infants represented two different types of social hierarchies between the conflicting agents.

High-rank agents tend to have more control over resources as well more social influence on other members' behavior than low-rank agents in hierarchical groups. Tracking the social power of different agents is a useful strategy that allows to infer agents' social status, and consequently, agents' roles as leaders or followers (Fragale, Overbeck, & Neale, 2011; Kwaadsteniet & Dijk, 2010; Magee & Galinsky, 2008). However, there are two ways to prevail in conflict situations: by dominance or by prestige. Dominant-subordinate relationships are based on the imposition of some agents over others, for instance by using their physical attributes. Prestigious relationships are based on the exchange of benefits between prestigious agents and group members. Prestigious agents are competent individuals that benefit all the group members. In return, group members allow prestigious agents to collect more resources (Cheng, Tracy, Foulsham, Kingstone, & Henrich, 2013; Gil-White & Henrich, 2001). Several authors have proposed that leaders' and followers' roles emerge from dominant-subordinate relationships (Padilla, Hogan, & Kaiser, 2007; Vugt et al., 2007). Nevertheless, these theories do not explain the full range of situation defined as leader-follower interactions. When group members can freely choose whom to follow, they often select agents whose leadership will benefit them, prestigious agents (Boehm et al., 1993; Price & Van Vugt, 2014). We suggest that in our study infants represented the winner as the high-rank agent in both types of familiarization. Critically, the way agents prevailed in the conflict situation labeled them as dominant or prestigious individuals. When the winner prevailed with explicit physical dominance, it was represented as a dominant agent. In contrast, when the winner prevailed without explicit physical dominance, it was represented as a prestigious agent. Therefore, the representation of both types of winners influenced infants' expectations about who the observer was going to follow in the path-following scenario.

To be aggressive or to be the one who explicitly takes something from others may be perceived as morally wrong (Hamlin, 2013; Van de Vondervoort & Hamlin, 2016). An alternative interpretation of our results could be that infants perceived the winner in the physical dominance condition as morally wrong. Although, the results of the physical dominance context do not support such explanation, as infants did not show significant differences between the two outcomes (see figure 2), our experiment was not designed to test this possibility. A way to discard this alternative interpretation would be to test infants' expectation about agents' affiliation in a neutral context. After familiarizing infants with the physically dominant agent, we would test infants' expectation about who the observer would approach (Geraci & Surian, 2011; Hinten, Labuschagne, Boden, & Scarf, 2018). Considering that infants expect other agents to affiliate with "good" agents and to avoid "bad" ones; if infants represented the winner by physical dominance as a bad agent, a test of affiliation would show that infants expect the observer to avoid the winner and to approach the loser (Hamlin, 2013).

This study is the first one exploring infants' expectations about the relation between agents' social power and their roles within the group. It shows that infants perceive as leaders agents with more resources; however infants are sensitive to the way agents obtained such resources. However, still unknown if infants also expect that agents identified as leaders get more resources in conflict situations. Leader-follower relationships are maintained across time by the free exchange of benefits between the agents. Followers profit from leaders' competence; in return of these benefits, leaders are allowed to get more resource by their followers. While it has been shown that 17-month-old infants expect high-rank agents prevailing in conflict situations to get more resources (Enright, Gweon, & Sommerville, 2017), there is no evidence of similar intuitions regarding non-conflict scenarios such as leader-follower interactions. Future studies should shed light on the origin of the representation of relationship between agents' social power and leadership roles.

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AUTHOR CONTRIBUTIONS

Jesus Bas and Nuria Sebastian-Galles developed the study concept and designed the experiments. Testing, data collection and statistical analysis were performed by J. Bas. J. Bas and N. Sebastian-Galles interpreted the results and wrote the manuscript.

All authors approved the final version of the manuscript for submission.

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Infants' representation of social hierarchies. From social power to leadership (Supplementary Information)

Table S1. Means and CI of the raw data in seconds and means and CI of the base-10 log-transformed data

	Non-Physical Dominance		Physical Dominance	
	Winner-Leader	**Loser-Leader**	**Winner-Leader**	**Loser-Leader**
Raw data in seconds	10.753 [2.17; 32.58]	1.713 [6.24; 30.93]	13.388 [4.58; 47.86]	14.735 [3.37; 27.13]
Base-10 log-transformed data	0.937 [.34; 1.51]	1.154 [.80; 1.49]	1.033 [.30; 1.68]	1.0755 [.36; 1.43]

Table S2. Raw data in seconds of all the participants

Non-Physical Dominance		Physical Dominance	
Winner-Leader	**Loser-Leader**	**Winner-Leader**	**Loser-Leader**
3.62	6.24	20.31	5.13
18.86	17.31	8.1	7.62
15.37	30.93	11.96	4.65
9.68	13.37	17	3.37
13.09	23.137	47.86	26.72
9.41	8.72	6.72	3.75
2.17	21.72	7.96	19.2
10.72	20.05	24.86	25.31
11.89	17.13	8.86	27.13
6.58	17.65	7.79	14.41
32.58	17.17	18.74	25.09
8.24	12.86	6.24	17.37
5.27	20.034	5.79	19.44
4.17	6.79	7.65	9.03
15.75	10.1	9.79	16.65
4.65	8.2	4.58	10.89

Table S3. Base-10 log-transformed data of all the participants

Non-Physical Dominance		Physical Dominance	
Winner-Leader	**Loser-Leader**	**Winner-Leader**	**Loser-Leader**
0.5587	0.795	1.307	0.710
1.275	1.23	0.908	0.881
1.186	1.490	1.077	0.667
0.985	1.126	1.230	0.527
1.116	1.364	1.679	1.426
0.973	0.940	0.827	0.574
0.336	1.336	0.900	1.283
1.030	1.302	1.395	1.403
1.075	1.233	0.947	1.433
0.818	1.246	0.891	1.158
1.512	1.234	1.272	1.399
0.915	1.109	0.795	1.239
0.721	1.301	0.762	1.288
0.620	0.831	0.883	0.955
1.197	1.004	0.990	1.221
0.667	0.913	0.660	1.037

3. EXPERIMENTAL SECTION II

a. Influence of agents' social status on 18-to-21-month-old infants' learning

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This article is currently in preparation

ABSTRACT

Infants often receive incongruent information from different adults. In order to select which information is the most relevant one, infants track adults' identity on the basis of their prestige, group membership or past accuracy. Here we study if infants from 18 to 21 months old are influenced by informants' social status when are learning. Infants' eye-behavior was recorded while two agents with different social status taught where several rewards could appear on the screen after an auditory cue. During the test phase, the auditory cues and the rewards where presented, but not the agents. Results showed an early (first fixation) and late (longer looking time) preference towards high rank agent's teachings. These results evidenced that as soon as infants can represent agents' social status their learning is influenced and are biased toward high-rank agents' teachings.

INTRODUCTION

Humans are defined as social learners because of their ability to learn through other individuals. This ability is critical during childhood when fundamental knowledge is acquired (Banaji & Gelman, 2013; Boyd, Richerson, & Henrich, 2011; Tomasello, 2000; Tomasello, Kruger, & Ratner, 1993). However, new information is often inconsistent with what we already know or what others have already taught us. To correctly select what to learn and from whom, humans have developed several learning biases (Boyd & Richerson, 1985; Henrich & McElreath, 2003; Laland, 2004). Learning biases are divided into content biases (what information we learn) and context biases (from whom we learn). Content biases are triggered by the type of information we are learning. For instance, similarly to other animals, humans retain very easily information related to survival (e.g. fear to dangerous animals). Context biases refer to how common is what the models try to teach us (Frequency-dependent biases) and the features of the model itself (Model-based biases).

Several features make some models more relevant than others (for a review, see Wood, Kendal, & Flynn, 2013). Children, as well as infants, to pay attention to individuals that communicate information using ostensive cues such as pointing, eye gaze, or using infant-directed speech (Behne, Carpenter, & Tomasello, 2005; Cooper & Aslin, 1990; Csibra & Gergely, 2009; Senju & Csibra, 2008). From all potential informants, humans are biased to learn from socially closer ones. Children, especially the younger ones, prefer information provided by their caregivers or familiar models rather than information provided by strangers (Corriveau, Harris, et al., 2009). Similarly, several studies have shown a bias towards the information provided by people from the same group speaking the same language dialect (in-group members) (Buttelmann, Zmyj, Daum, & Carpenter, 2013; Kinzler, Corriveau, & Harris, 2011). It has been argued that the bias towards in-group members is due to adaptive reasons, both instrumental and social (for a debate, see Begus, Gliga, & Southgate, 2016, 2017; Kinzler & Liberman, 2017).

From an adaptive point of view, learning from the most competent models is the best strategy (Chudek, Heller, Birch, & Henrich, 2012). They are the individuals who possess the knowledge, ability or skills necessary to face and succeed environmental challenges (Gil-White & Henrich, 2001). How humans are biased towards competent models has been widely addressed. Models' accuracy, that is the probability of performing properly a task, has been shown to influence children's trustworthiness towards those models. Children who receive conflicting information about the label of an object or its function trust more models that, in a similar task, showed better performance in the past (Koenig & Harris, 2007; Zmyj, Buttelmann, Carpenter, & Daum, 2010). To assess models' performance, it is necessary to evaluate their actions regarding the task as correct or incorrect (Corriveau & Harris, 2009; Corriveau, Meints, & Harris, 2009; Koenig & Harris, 2005a). This evaluation may be difficult for children, specially the younger ones, because of their lack of knowledge (Corriveau, Meints, et al., 2009; Koenig & Harris, 2005b). A way to solve this problem is by trusting agents perceived as more successful, even if their specific competence in the task at hand is unknown. Examples of such biases are the trend to copy from older rather than younger models, from models that show a high-self-confidence or that are identified as high-rank individuals within a social group (Matsui, 2001; Matsui, Yamamoto, & McCagg, 2006; Rakoczy, Hamann, Warneken, & Tomasello, 2010).

Social rank is defined as the position that one individual occupies within the social network of one group (Fragale, Overbeck, & Neale, 2011; Magee & Galinsky, 2008). Hierarchical structure can facilitate the interaction between group members, influencing their cognitive processes and providing, in some cases, individual and collective benefits (Halevy, Chou, & Galinsky, 2011). Several authors have demonstrated that infants are able to identify the high rank agent in a context where two agents share the same goal but only one of them can achieve it. The prevailing agent is identified as the high rank one and her role is viewed as stable across time. Thomsen, et al. (2011) showed that 10-month-old infants expect bigger agents to prevail over smaller ones. Mascaro and Csibra (2012) were the first authors to show that infants are also able to infer the social status of two agents regardless their observable physical appearance. The results of a first study showed that 12-month-old infants expect agents who prevail in one conflicting task (to collect items) to continue prevailing in future similar conflicts. A second study showed that 15-month-old infants also expect agents who physically prevail in one conflicting task (to remain in a delimited area) to continue prevailing in a task of a different domain (to collect items). More recently, Bas and Sebastian-Galles (submitted) showed that providing information about agent's social power (and in the absence of physical cues of dominance) infants do not represent hierarchical relationships as stable across domains before 18 months of age.

Different authors have already shown how the social status of different agents influences learning. McGuigan (2013) showed that

5-year-old children over-imitate more easily high-status agents (a head teacher) than low-status ones (a class teacher). Similarly, Chudek et al., (2012) found that 4-year-old children tend to copy the actions of prestigious agents, defined as agents receiving more visual attention from others (see also Fusaro and Harris (2008)). Bernard et al. (2016) investigated social status based on physical dominance and showed that at 3-years of age children begin to consider agents' social status when they have to endorse a testimony (see also Castelain et al. (2016)). These studies provide evidence that from 3 years of age children are biased to copy individuals targeted as high-rank agents, however as just reviewed, the capacity to recognize the social status of other individuals emerge earlier in development.

Considering that infants' capacity to represent the social status of several agents emerge during the second year of life, we investigated if infants from 18 to 21 months of age are already biased to learn from high rank agents. We used the same procedure as Bas and Sebastian-Galles (submitted) to show infants the social status of two agents. Next, we tested the influence of agents' social status on infants' learning by adapting Tummeltshammer et. al (2014)'s procedure. We adapted Tummeltshammer et al., (2014)'s procedure because it allows working with very young infants as it does not require infants to speak as other procedures do (Kinzler et al., 2011; Koenig & Harris, 2005a). Bas and Sebastian-Galles (submitted) showed infants that two agents are able to grab different stuffed animals when they try it individually. When both agents try to grab the same stuffed animal at the same time, only one of the agents prevails (the high-rank agent). Tummeltshammer et al. (2014)'s procedure consists in a series of trials where two models separately teach where different animals are going to appear on the screen after an auditory cue. These authors manipulated the accuracy of each agent in pointing the correct location where the animals appeared. In the test phase, they measured infants’ eye-behavior when models cued different locations after new auditory cues were presented. In our adaptation we do not manipulate models' accuracy as both agents always teach correctly where the animals will appear. During the learning phase, each agent cues where an animal is going to appear on the screen. Each agent cues the appearance of one of two animals: a cow or a sheep (*individual rewards*). Importantly, there is a third animal that each agent cues in a different location: a cat (*conflicting reward*). In the test phase, only the sounds and the pictures of the animals are presented but not the agents. Critically, the third animal is presented in both cued locations at the same time. We hypothesize that infants will learn similarly from the two agents regardless of their social status. However, when the information provided by the two agents conflicts, infants will be biased towards the high-rank agent' teachings. Thus, we expect that during the test, infants are going to look first and for a longer period of time the location cued by the high-rank agent. Individual rewards will be used as a control of infants' eye-behavior and we do not expect significant differences during the test.

METHODS

The research reported in this manuscript has been conducted in accordance with the principles expressed in the Declaration of Helsinki and approved by the local ethical committee (The Clinical Research Ethical Committee of the Parc de Salut Mar). All parents signed an informed consent for their infants to participate in this study.

Participants

Participants were recruited by visiting maternity rooms at private hospitals, Hospital Quirón and Clínica Sagrada Família in Barcelona, Spain. All participants were healthy, full-term infants (> 37 Weeks of gestation). Forty-eight infants from 18 to 21 months-old were retained for the analysis (23 boys, M = 19, SD = 10 days). Thirty-two additional infants were tested but excluded from the final analysis because they did not finish the whole experiment (9); did not generate data points during one repetition of the establishment of the social hierarchy (2); did not generate data points during two repetitions of the learning phase (2); did not complete the test phase (4); less than 50% of eye-tracker data obtained during the whole experiment (6); because of parental interference (4) experimental error (5).

Stimuli and procedure

Figure 1 illustrates the experimental procedure. The study consisted in three phases: a) Establishment of the Social Hierarchy, b) Learning Phase and c) Test phase. A preference for each agent was measured at the beginning of the experiment, after the establishment of the social hierarchy and at the end of the experiment. Between each stimuli (video and images), a fixed cross at the center of the screen was presented for 0.5 seconds. Total duration of the experiment after the calibration was approximately 5 minutes.

<u>Preference tests (a1, a2 and a3 in figure 1)</u>

A picture of each agent's face was used to measure infants' preference for each agent. Both agents' pictures were simultaneously presented for 5 seconds. Each agent appeared on the side where they would appear subsequently.

Establishment of Social Hierarchy (b1, b2 and b3 in figure 1)

All the videos started by showing the same scenario. A stuffed animal was on a table located in the middle of an empty room.

The establishment of social hierarchy was subdivided in two parts. In the first one (individual contexts, b1 and b2 in figure 1), each agent entered the scene from one of the sides and greeted to the camera by waving her hand and smiling (7 s). Next, she looked at the stuffed animal and approached to get it. Finally, she moved forwards smiling (5 s). The whole sequence lasted 12 s.

In the second part (conflict context, b3 in figure 1) both agents appeared from their corresponding sides and simultaneously greeted to the camera (7 s). Next, they looked at the stuffed animal and approached it at the same time. During the following 5 seconds, both agents performed the same sequence of actions in a synchronized way. First, they touched the stuffed animal and then they looked at each other, this action was repeated twice. Then, the high-ranked agent took the stuffed animal and moved forward smiling (3 s). Then, the low-ranked agent stepped back and bended her head (4 s). The whole sequence lasted 19 s

This sequence (establishment of social hierarchy and conflict context) was repeated three times; in each one the stuffed animal was different to facilitate the generalization of the social hierarchy across time and task. For the individual contexts we presented the high-ranked agent first and then the low-ranked one.

Learning Phase (c1a, c1b, c2a and c2b in figure 1)

Trials of the learning phase started by showing a cross at the center of the screen on a grey background and one white box with a black frame at each corner of the screen. This phase consisted in five repetitions of 4-trial blocks. In each block, one of the agents appeared in the two trials and the other agent appeared in the other two trials. The sequence of a trial was as follows. After 0.5 s, the face of one of the agents appeared at the center of the screen looking to the front during 1s. Then, an auditory cue (the sound of an animal) sounded during 2 s. After the auditory cue, the agent oriented her gaze to one of the white boxes (the movement lasted 0.5 s). After 0.5 s a drawing of the corresponding animal was displayed on the gazed box (the reward). The drawing zoomed in and out while its sound was repeated during 2 s. At the end of the sound, the agent directed her gaze to the front (the movement lasted 0.5 s) during 1 s while the drawing of the animal remained in view.

Each agent was paired with either a cow or a sheep and with one of two cats. On the top-right a sheep (i.e. High-rank individual reward, c1 in figure 1), on the top-left appeared a cow (i.e. Low-rank individual reward, c2 in figure 1), and on the bottom boxes appeared the same cat (i.e. High and Low conflicting reward, c3 and c4 in figure 1). Within each block agents' appearance was randomized.

To facilitate learning each agent always looked to the side of the screen where she had appeared in the previous phase. Agents' roles, individual rewards and locations were counterbalanced across participants.

Test Phase (d1, d2 and d3 in figure 1)

The test phase was similar to the learning phase except that there was a white dot at the center of the screen instead one of the agents. All the trials started by showing a cross at the center of the screen on a grey background and one white box with a black frame at each corner of the screen. After 0.5 s, a white dot appeared at the center of the screen and after 1s the sound of one of the three animals was produced during 2 s. After 1 s, the drawing of the corresponding animal was displayed in one box and zoomed in and out while its sound was repeated during 2 s. The drawing remained in the box 1,5 seconds before the trial ended. Animals appeared in the same places as in the learning phase. Critically, the conflicting rewards (the two cats) appeared in the two bottom boxes simultaneously. This sequence (block) was repeated twice. The order of appearance of each reward was randomized in each block.

Apparatus

Infants were tested at the "Laboratori de Recerca en Infància", from the Center for Brain and Cognition at Universitat Pompeu Fabra, Barcelona. Infants sat on their caregiver's lap at approximately 65 cm from the screen in a sound-attenuated room. The session was recorded with a video camera (Sony HDR-HC9E). All stimuli were presented using Matlab's Psychtoolbox-3 software on a 23" screen and gaze was measured using a Tobii TX300 near infrared eye-tracker, recording at a frequency of 120 Hz. Before each recording the eye-tracker was calibrated using five-points of reference. Videos were presented on a full screen with a resolution of 1920 x

1080 pixels on a 23" screen; photos were 15 x 10 cm and they were presented at 5 cm from the center of the screen.

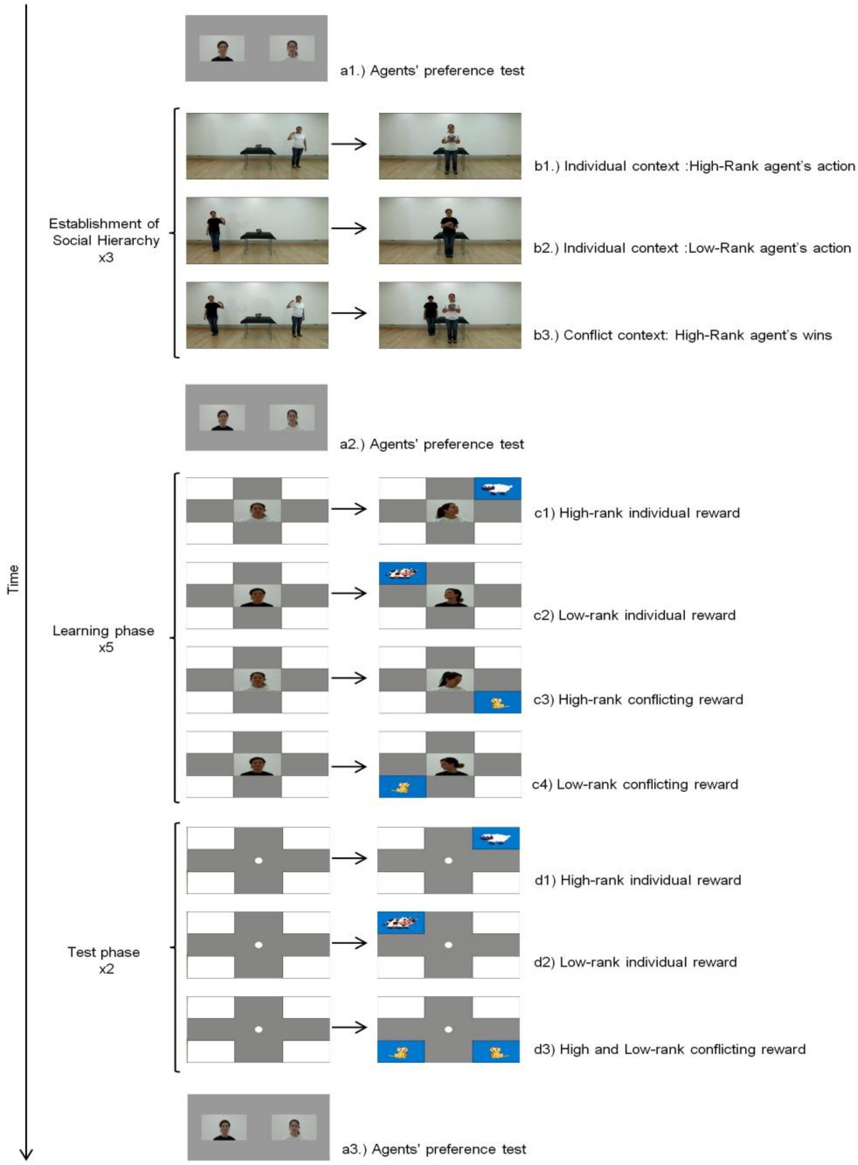

Figure 1. Stimuli presentation procedure. The experiment was divided in several phases: Preference test (a1, a2, a3), Establishment of Social Hierarchy (b1, b2 and b3), Learning phase (c1, c2, c3 and c4) and Test phase (d1, d2, d3). See the main text for a full description.

Data analysis

Different data analyses were conducted for each phase of the experiment, using the Total Looking Time to the Screen or the Total Looking Time to different Areas of Interest as dependent variables. To calculate the Total Looking Time to an Area of Interest we divided the time infants spent looking at a specific area of the screen by the time infants spent looking at the whole screen.

For the preference tests we calculated the Total Looking Time to the two Areas of Interest determined by the areas occupied by the agents' pictures (High-Rank Agent and Low-Rank Agent). For the establishment of the social hierarchy and for the learning phase the Total Looking Time to the whole Screen for each video was used.

The test phase was subdivided in two time intervals: before and after the appearance of the rewards. For the first interval, we calculated Total Looking Time to the whole screen. Following Chow et. al (2016), we divided the second interval into two-time windows; for each one we calculated the Total Looking Time to the four different Areas of Interest corresponding to the boxes where the animals could appear: Individual High-Rank Animal (reward taught only by the high-rank agent), Individual Low-Rank Animal (reward taught only by the low-rank agent), Conflicting High-Rank Animal (reward taught by the high-rank agent conflicting with the taught by the low-rank agent), Individual High-Rank Animal (reward taught by the low-rank agent conflicting with the taught by the high-rank agent).

We also determined the first fixation to one of the four areas of interest once the reward appeared in the second interval. The first fixation corresponded to the first continuous looking time equal or longer to 250 ms to the same Area of Interest (Kowler, 2011). If infants looked where the reward appeared (accurate fixation) we assigned a score of 1, otherwise it scored 0 (inaccurate fixation).

RESULTS

To assess if infants were paying equivalent attention to the videos in the Establishment of Social Hierarchy and Learning phases (b1, b2 and b3; c1, c2, c3 and c4 in figure 1), we calculated the total looking times to each video and compared one by one those portraying the high rank agent versus the ones portraying the low rank agent with a T.test analysis. We did not find any difference. Also, we observed equivalent looking times to the two agents in the preference tests (a1, a2 and a3 in figure 1). During the first part of the test phase, before the appearance of the rewards (d1, d2 and d3 in figure 1), infants also behaved similarly in all the trials. Next, we present the results of the analysis of the second part of the test phase when the rewards appeared (d1, d2 and d3 in figure 1).

First Fixation Analysis (Figure 2),

We collapsed the frequency of accurate and inaccurate fixations in the two blocks of the test phase as a McNemar's (Fagerland, Lydersen, & Laake, 2013) test showed no differences between the blocks.

A binomial test showed that the proportion of accurate fixation was higher than 25% ($p < 0.001$) when the individual high rank animal and the individual low rank animal appeared. We compared the number of accurate fixations to the individual high rank animal versus the number of accurate fixations to the individual low rank animal. Results showed that there were more accurate fixations regarding the individual high rank animal than the low rank animal ($p < 0.001$).

For the conflicting rewards, a binomial test showed that the proportion of accurate fixations (independently if it was the conflicting high rank animal or the conflicting low rank animal) was higher than 50% ($p < 0.001$). A binomial test showed that the proportion of accurate fixations to the conflicting high rank animal versus the conflicting low rank animal. Results showed that the fixation to the high-rank agent's reward was higher than 50% ($p = 0.006$

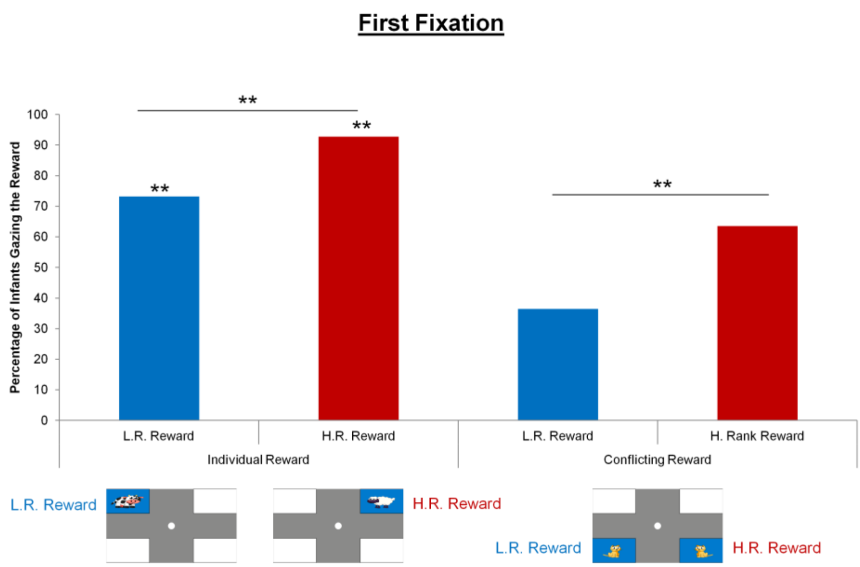

Figure 2. First fixation. The first fixation corresponded to the first continuous looking time equal or longer to 250 ms to the same Area of Interest after the reward appearance.

Total Looking Time Individual Rewards (Figure 3)

For the individual rewards (d1 and d2 in Figure 1), the data from both blocks were collapsed after confirming there were no differences between blocks. A repeated measures ANOVA was computed to analyze the Total Looking Time to the different Areas of Interest based on 3 factors: Rank (High vs Low Rank Agent), Time Window (First or Second Time Window) and the four Areas of Interest where the rewards could appear (Individual High-Rank Animal, Individual Low-Rank Animal, Conflicting High-Rank Animal, and Individual High-Rank Animal). The ANOVA showed a triple interaction between Rank, Time Window and Area of Interest $F(3,138)= 11.214$, $p<0.001$, $\eta^2_p= 0.999$).

Infants looked longer to the Area of Interest where the reward appeared independently of the agent who taught it (see statistics in Table 1 and Figure 3). We compared the differences between the rewards taught by each agent. Results showed that during the First Time Window infants looked always at the center of the screen. In the Second Time Window they looked longer at the reward associated to the High Rank Agent (Mean H.R.=0.883; Mean L.R.= 0.774; ($t(46) =2.628$, $p=0.012$, 95% CI [0.192, 0.025], $d= 0.379$). Infants looked longer at this area in Second Time Window than in the First Time Window (Mean First Time Window =0.752; Mean Second Time Window =0.883; ($t(46) =5.125$, $p=0.000$, 95% CI [0.183, 0.08], $d= 0.739$)).

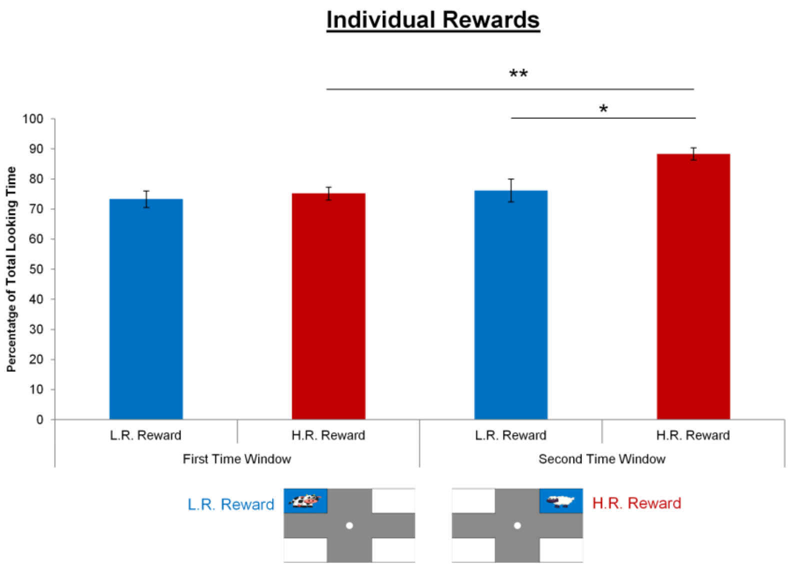

Figure 3. Percentage of Total Looking Time to the Area of Interests corresponding the boxes where the animals appeared in the individual rewards.

Total Looking Time Conflicting Rewards (Figure 4)

For the conflicting reward (d3 in Figure 1), data from both blocks were collapsed once confirming there were no differences between blocks. A mixed repeated measure ANOVA was computed to analyze Total Looking Time to the different Areas of Interest based on 2 factors: Time Window (First or Second Time Window) and the four Areas of Interest where the rewards could appear (Individual High-Rank Animal, Individual Low-Rank Animal, Conflicting High-Rank Animal, Individual High-Rank Animal). Results showed a double interaction between Time Window and Area of Interest ($F(3,135)= 8.329$, $p<0.001$, $\eta^2_p= 0.992$).

Based on our hypothesis, we compared the total looking time to the four Areas of Interest. In the First Time Window infants looked significantly longer to the Areas of Interest where the rewards appeared (bottom boxes) but no differences between the two boxes where the individual rewards appeared was found. In the Second Time Window infants looked longer to the reward associated with the high rank-agent than to the one associated with the low-rank agent (Mean H.R.=0.529; Mean L.R.=0.357; (t (45) =2.975, p=0.005, 95% CI [0.055, 0.289], d= 0.429). Infants looked longer at this area in Second Time Window than in the First Time Window (Mean First Time Window =0.374; Mean Second Time Window =0.529; (t (45) =4.007, p=0.000, 95% CI [0.242, 0.0803], d= 0.578)).

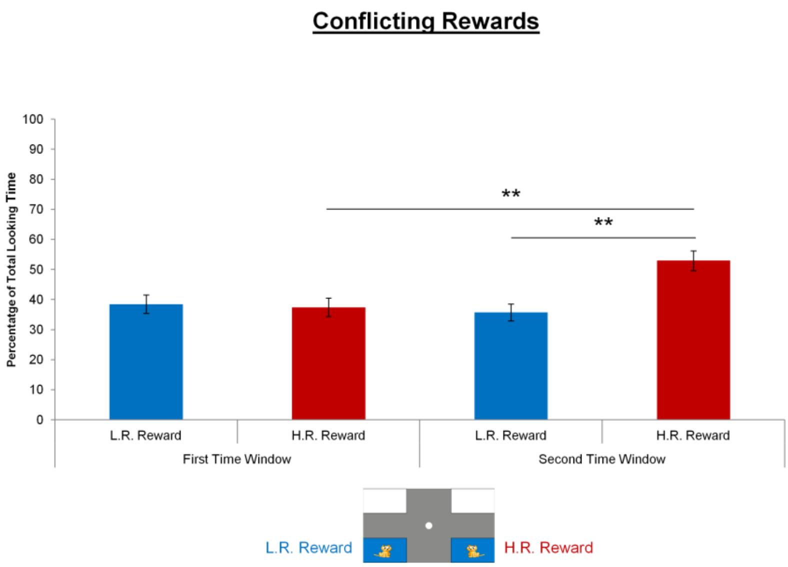

Figure 4. Percentage of Total Looking Time to the Area of Interests corresponding the boxes where the animals appeared in the conflicting rewards.

DISCUSSION

Eighteen-month-old infants are able to represent social hierarchies from observed interactions between different agents (Bas & Sebastian-Galles, submitted; Mascaro & Csibra, 2012). However, little is known about how this representation influences other cognitive processes, in particular learning. We have provided evidence that models' social status influences infants' learning. We presented infants two agents with different social status showing where different rewards were going to appear on the screen after an auditory cue. Next, we measured infants' eye-behavior during the appearance of the rewards, in the absence of the models. Results showed that when the conflicting-rewards were presented simultaneously on the screen, infants tended to gaze first (first fixation) the reward taught by the high-rank agent and that at the end of the trial they looked longer at this reward (second time window). We also measured infants' gaze behavior during the presentation of the individual (non-conflicting) rewards. Results showed that infants accurately searched the rewards' location on the screen (first fixation) independently of who had taught it. Surprisingly, there were more accurate fixations for the individual high-rank reward. Infants also looked longer at the individual high-rank rewards at the end of the trials (second time window). Taken together, the results of the present investigation suggest that infants' learning is influenced by the agents' social status, although they learn from each individual separately.

Humans as social learners learn from individuals perceived as potential informants (Wood et al., 2013). When several agents provide non-conflicting information, infants learn from all of them. However, when the information provided by the agents is in conflict, infants have to select from whom to learn (Koenig & Harris, 2005b). In these situations, several properties of agents' identity guide infants' preference; for instance, agents' social group or agents' past accuracy in similar tasks (Corriveau & Harris, 2009; Kinzler et al., 2011). Our study confirmed that infants are also biased towards teachings provided by high-rank agents. We suggest that this is due to the existence of an indirect bias towards the high-rank agent (Boyd & Richerson, 1985). That is, infants assume that high-rank agents are competent in domains non-related with the domain in which they actually showed to be competent (Brosseau-Liard & Birch, 2010; Cain, Heyman, & Walker, 1997; Miller, 2000). It remains unknown what happens when both models are recognized as high-rank ones in different domains. We hypothesize that in that case infants will copy each model in their specific domain of expertise (Seehagen & Herbert, 2012; VanderBorght & Jaswal, 2009; Wood et al., 2013), but it is uncertain who would be copied in unrelated domains.

Our initial hypothesis held that only when infants receive conflicting information from different agents, they have to select one of them. We observed that infants were biased to high-ranking agents' teaching even in non-conflict situations. This bias may reflect differences in the encoding of the information provided by the high rank agent (Frith & Frith, 2012; Mitchell, Macrae, & Banaji, 2004; Tulving & Thomson, 1973). Studies with adults have shown that high-ranked agents receive more attention than low-ranked ones. Because visual attention increases sensory processing by reducing and optimizing encoding time, information provided by high rank agents is better processed (Dalmaso, Pavan, Castelli, & Galfano, 2012; Foulsham, Cheng, Tracy, Henrich, & Kingstone, 2010;

Santamaría-García, Pannunzi, Ayneto, Deco, & Sebastián-Gallés, 2014; Santamaría García, Ayneto, & Sebastián Gallés, 2013; Zink et al., 2008). Our results suggest that such attentional biases towards high-rank agents may emerge in infancy. However, our investigation was not specifically designed to test if attention is influenced by the models' social status and the present explanation remains speculative.

The present investigation has provided evidence of an early bias to learn from high rank individuals. We have tested infants at the youngest age they are able to represent social hierarchies in the absence of cues of physical dominance (Bas & Sebastian-Galles, submitted). Due to the adaptive relevance of agents' social status as a cue to select informants, we hold that such bias emerges as soon as infants are able to represent social hierarchies. Our investigation does not inform about the existence of an earlier bias when hierarchical relations are based on physical dominance. Infants seem to prioritize different types of social cues (Kinzler, Shutts, & Correll, 2010; Liberman, Woodward, & Kinzler, 2017) and such social cues appear at different moments in development. Dominant-subordinate relationships based on the physical properties of agents are represented earlier than those relationships not based on physical dominance (Mascaro & Csibra, 2012; Thomsen et al., 2011). Given the earlier emerge of the representation of social relations based on physical dominance; infants may show an earlier learning bias in the case a social hierarchy is based on physical dominance. When and how other types of social hierarchies influence infants' learning still unknown.

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AUTHOR CONTRIBUTIONS

Jesus Bas and Nuria Sebastian-Galles developed the study concept and designed the experiments. Testing, data collection and statistical analysis were performed by J. Bas. J. Bas and N. Sebastian-Galles interpreted the results and wrote the manuscript. All authors approved the final version of the manuscript for submission.

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4. DISCUSSION

The present dissertation aimed to explore the relationship between social hierarchies and learning process during infancy. In order to do so we performed a series of three studies exploring infants' capacity to represent social hierarchies, while a fourth study targeted the main question of the thesis. In the following, we will summarize the results of each study separately and we will connect them to propose a comprehensive interpretation. In the last section, first, we will discuss unsolved issues in this dissertation and second, we will propose new research directions presenting a specific proposal of new studies.

a. Summary of findings

i. Infants' representation of social hierarchies in absence of physical dominance

Several cues allow humans to identify the social status of their conspecifics. One of the most reliable cue is the success of the agents in agonistic contexts. Different authors showed infants' capacity to recognize the social status of two conflicting agents and to make predictions about who is more likely to prevail (Mascaro & Csibra, 2012; Pun, Birch, & Baron, 2016; Thomsen, Frankenhuis, Ingold-Smith, & Carey, 2011). In these studies, the authors manipulated different properties of the agents, such as their body size, the size of the group agents belonged to or who prevailed in past interactions (requiring force). One common property of these studies is that all the cues of social status were associated to physical properties of the agent. Therefore, the previous studies showed that infants expect that physically dominant agents prevail.

In our first study we wanted to go a step forward demonstrating that the presentation of the agents' social power is enough to allow infants to make predictions in agonistic contexts (Magee & Galinsky, 2008). We adapted the procedure of Mascaro and Csibra (2012) and presented 15- and 18-month-olds' infants two physically similar human agents competing to grab a teddy bear. The same (high-ranked) agent always prevailed over the other (low-ranked) agent. Critically, agents' interactions did not involve any type of physical dominance. In the test phase, the same agents competed to seat on an armchair. We compared infants' attention when the high-ranked agent won (Congruent output) to when the previously lower-ranked agent won (Incongruent output).

Results showed that 18-month-old but not 15-month-old infants increased their attention looking at the low-ranked agent prevailing in the second context. We concluded that 18-month-old infants were able to represent the conflicts between the two agents and make inferences about who was most likely to win when there were no physical cues of social dominance. We suggested that the delay in the capacity of infants to represent the social status of both agents in our study, in comparison to the other ones, is because it requires infants to represent the social power of each agent and to generalize it through contexts. This representation is more demanding than only recognizing agents' physical properties. An alternative interpretation could be that infants were representing a prestige-based relationship. Prestige relationships are more complex than dominance-subordinate relationships; they are based on the exchange of benefits between the agents involved, not on the imposition of one agent's will over the others. (Cheng, Tracy, Foulsham, Kingstone, & Henrich, 2013a).

ii. Infants' representation of leader-follower relations

Social hierarchies are ubiquitous in human relationships since infancy and help to regulate individuals' behaviours and interactions. As just said recent research has demonstrated the capacity of infants to represent hierarchical in agonistic contexts (Mascaro & Csibra, 2012; Pun et al., 2016; Thomsen et al., 2011). Less is known about infants' capacity to represent other forms of social hierarchies such as leader-follower relationships. Leaders are agents who significantly influence other agents' behaviour, named followers (King & Cowlishaw, 2009; Smith et al., 2016) .

In our second study, we explored infants' capacity to represent these leadership relations. We presented 12-15- and 18- month-old infants with a scenario with four animated cartoon agents in which two of them performed different actions (e.g., one jumped, the other moved from side to side). Later, the other two agents (the followers) consistently imitated the action performed by one of the first two agents (the leader), and ignored the action performed by the other agent (the non-leader). We measured infants' expectations in two novel test situations. In the incongruent test event, one of the followers failed to follow the leader. In the neutral test event, the leader failed to follow one of the followers. Infants' looking time at the screen was measured during the test events.

Results showed that infants aged from 12 to 18 months looked longer at the incongruent than at the congruent event. It suggested that infants expected that agents who imitated the movement of the leader in the first context to follow the leader's path in the second context. Thus, infants from 12 months of age on are already able to represent leader-follower relations and to understand this type of relationship as asymmetrical; leaders influence followers, but not the reverse. Infants also expect these relations to display stability over time, even in the absence of an explicit punishment or reward to the follower.

ii. Infants' representation of social hierarchies. From social power to leadership

Previous studies have shown that infants are able to represent hierarchical relations regulating conflict (Mascaro & Csibra, 2012) and hierarchical relations regulating collective actions (Bas et al., submitted). However, little is known about how both representations relate to each other.

In our third study we explored infants' intuitions about the relation between the social power of several agents and their leadership role. We presented 18-month-old infants a scenario in which one animated cartoon agent (observer) watched how two other animated cartoon agents successfully picked up several balls one after the other. Then the two agents tried to pick a ball up at the same time and the same agent prevailed always. Critically, we manipulated how the winner prevailed (with or without physical dominance). After the familiarization, the observer followed one of the agents - either the "winner" or "loser". We measured infants' looking time to the screen when the observer followed one of the agents.

Results showed that infants looked longer when the observer did not follow the winner, but only if the winner prevails without physical dominance. We interpreted the results as proving that infants link both types of social hierarchies. In addition, they suggest that infants can recognize different ways to prevail in conflict situations, by the use or not of the force. These results open the door to new studies addressing infants’ capacity to represent agents' behaviours and the social relationships that emerge from them.

iv. Influence of agents' social status on 18-to-21-month-old infants' learning

Infants often receive conflicting information from different adults; the way infants solve such situations is by relying on different types of cues, in particular agents' past accuracy or their social group membership (Corriveau, Meints, & Harris, 2009; Koenig & Harris, 2005, 2007; Kristen Swan Tummeltshammer, Wu, Sobel, & Kirkham, 2014). Several studies showed that children are also biased to learn from high-rank agents (Bernard et al., 2016; Castelain, Bernard, Van der Henst, & Mercier, 2016; Chudek, Heller, Birch, & Henrich, 2012). Despite social hierarchies are represented before the second year of age, there are no studies addressing such type of bias during infancy.

In our fourth study we explored the influence of agents' social status in 18- and 21-month-old infants' learning. We designed a procedure that consists of three parts. In the first part, a video showed two human agents competing for the same goal. The same high-rank agent always prevailed. In the second part, the face of one, or the other, agents appeared in the centre of the screen followed by and auditory cue (the sound of an animal). Then the agent looked at one of the corners of the screen and a drawing of the animal that previously had sounded appeared (adapted from Tummeltshammer et al. (2014)). In some cases, the information provided by the agents about where the animals were going to appear was in conflict. In the third (test) phase, only the sounds and the rewards appeared. We hypothesized that infants was going to be biased to the information provided by the high-rank agent. Results showed a first fixation and a longer total looking time to the rewards taught by the high-rank agent. Results suggest that as soon as infants represent the social status of the agents, it influences their learning.

In the following section we will discuss the reasons behind the bias to learn from high-rank agents by adding the results of the other studies of this dissertation.

b. Overall interpretation: Leaders influence learning during infancy

Regarding infants' representation of social hierarchies, our studies showed that infants are able to recognize the social status of two agents when they are conflicting in a resource allocation task and they represent that status as stable across time and tasks (study 1). Similarly, infants are able to represent leader-follower relationships, understanding that some agents influence significantly other agent's action and expecting this influence to be stable across time (study 2). Both types of relationships are related. Infants expect agents who prevail in conflict scenarios to be selected as leaders by third party agents (study 3). In our last study we showed that infants are biased towards the agents with a higher status who prevailed in conflict scenarios (study 4). The conclusion of the first three studies is that if infants represent high rank agents as leaders and understand that agents who are imitated are the leaders; high-rank agents are imitated too. This conclusion sets the ground for our fourth and fundamental study, in which we tested if infants' own behavior was influenced by high-rank agents. In other words, high-rank agents, as leaders, influence significantly infants' (learning) behavior.

Social hierarchies emerge naturally in most of social groups, that is why the capacity to recognize and represent them is very important. They regulate interactions between all the members and increase group and individual performance. High-rank agents are those who better deal with the problems arising in their environment (Cummins, 2015; Halevy, Chou, & Galinsky, 2011; Koski, Xie, & Olson, 2015). It has been widely evidenced the infants' capacity to represent social hierarchies (Mascaro & Csibra, 2012; Pun et al., 2016; Thomsen et al., 2011). We suggest that the tendency to learn from high rank agents emerges during infancy because during this period learning is a fundamental process and to learn from successful agents is adaptive from an evolutionary point of view (Bernard et al., 2016; Castelain et al., 2016; Chudek et al., 2012).

The bias of preferentially learning from successful individuals could be included within the model-based biases (Wood, Kendal, & Flynn, 2013). It would be defined as the tendency to learn from agents perceived as more competent. This bias is adaptive when individuals learn from competent (high-rank) individuals in their domain of expertise. Nevertheless, the same bias might be counterproductive when individuals take as models high-rank agents in a domain of expertise different to that that allowed them to attain their social status (indirect bias) (Brosseau-Liard & Birch, 2010; Cain, Heyman, & Walker, 1997; Rindos et al., 1985; Ulrich & Miller, 1993). It might be that this bias is a by-product of the cognitive processes underlying the learning process. In particular, because individuals unconsciously pay more attention to high-rank agents, they learn more from them than from low-rank agents (Dalmaso, Pavan, Castelli, & Galfano, 2012; Foulsham, Cheng, Tracy, Henrich, & Kingstone, 2010; Santamaría-García, Pannunzi, Ayneto, Deco, & Sebastián-Gallés, 2014). This explanation could explain why humans learn from high-rank agents even when it could be counterproductive.

Studies addressing learning biases are often designed to test children's explicit learning or preference for one model. As reviewed, in such studies children are taught first conflicting information by two teachers and then they are asked to actively select one of the them (i.e. Castelain et al., 2016; Chudek et al., 2012; Koenig & Harris, 2005). Such procedures are poorly adapted to test preverbal infants. In order to extend the comprehension of learning biases, and to test if they emerge from the cognitive processes mediating learning, it would be necessary to use other procedures. These procedures should to be able to evaluate infants' implicit learning, as well as to disentangle which cognitive processes are driving the bias (Cleeremans, Destrebecqz, & Boyer, 1998; Dienes & Berry, 1997; Sun, Slusarz, & Terry, 2005). One example of such procedure is our adaptation of Tummeltshammer et al., (2014). This experimental procedure allowed us to test preverbal infants (study 4). The same procedure could be easily modified to study the cognitive processes underlying the learning process.

Another question resulting from the bias to learn from high-rank agents is what happens when two models perceived as a high-rank provide conflicting information. According to the instrumentality function of learning (Legare & Nielsen, 2015; Over & Carpenter,

2013) individuals will copy the best model in each domain of expertise; however it is uncertain who would be copied in uncharted domains (Seehagen & Herbert, 2012; VanderBorght & Jaswal, 2009; Wood et al., 2013). However, it has to be considered that imitation also has social motivation. (Bernard et al., 2016; Legare & Nielsen, 2015; Over & Carpenter, 2013). Agents who act alike are expected to belong to the same social group (Liberman, Woodward, & Kinzler, 2017; Liberman, Woodward, Sullivan, & Kinzler, 2016; Powell & Spelke, 2013). It might be that individuals search social approbation from high rank agents and from other group members by imitating the high-rank agents. Individuals doing so would be perceived socially closer to high-rank agents, and consequently they would "get" part of their social status. In this line, Mascaro et al. (in prep.) studied how social status is derived from alliance relationships.

Gil-White and Henrich (2001) suggested that hierarchical relationships based on prestige emerge from the bias of learning from successful individuals. Individuals confer prestige to agents who possess the knowledge to succeed in their environment in order to acquire a greater access to the information they hold. Therefore, to establish prestige relationships, it is necessary to understand second-order benefits; it is beneficial to allow others to get more resources in order to gain other benefits (knowledge) (Price & Van Vugt, 2014). Several authors proposed that prestige relationships are only considered by humans due its direct relation to cultural learning. Contrary to most of the other social animals; humans learn from and are leaded by the most competent agents independently of their physical features (Cheng, Tracy, Foulsham, Kingstone, & Henrich, 2013b; Chudek et al., 2012; Gil-White &

Henrich, 2001; Price & Van Vugt, 2014). Despite in almost all of our studies we suggest that infants might be representing hierarchical relationships based on prestige, we did not show any strong evidence for it. As far as we know there are not studies addressing directly infants' representation of prestige.

c. Infants' intuitions about the characteristics of the leaders

Among all the questions remaining open in this dissertation, we want to focus on the ones that emerge from the second and third studies, related with the representation of leader-follower relationships during infancy. Next we expose a research proposal to expand those studies, trying to identify the features that leaders are expected to possess and to explore the computations linking social power and leadership.

Several authors have proposed that leaders and followers' roles emerge from dominant-subordinate relationships (Alexander, 1987; Blute & Wilson, 1976). Nevertheless, these theories do not explain the full range of situations defined as leader-follower interactions. When group members can freely choose whom to follow, they often select agents whose leadership will benefit them rather than dominant agents (Gil-White & Henrich, 2001; Price & Van Vugt, 2014). Conceptualizing leader-follower relationships as an exchange of benefits between individuals leads to predict the properties of leaders. A leader has to be able to achieve specific goals, but simultaneously, to be generous enough to share the benefits of these goals with the other members of the group.

In human past environments, physical fitness was crucial to succeed in activities such as hunting or war. Consequently, physical capability was a relevant factor when choosing a leader.

Nowadays, human adults are still biased to allocate leadership roles in agents with features cueing physical fitness, even the latter is irrelevant (Van Vugt, 2006). Previous studies have shown that infants can evaluate the difficulty of achieving a goal (Liu, Ullman, Tenenbaum, & Spelke, 2017), and that toddlers prefer agents that achieve their goals more easily (Jara-Ettinger, Gweon, Tenenbaum, & Schulz, 2015). Despite it has been shown that infants link physical fitness with a higher social status, no one has confirmed whether it is also linked to leadership roles.

Success does not depend only on physical fitness; some tasks require leaders to possess other skills in order to achieve their goals, such as intelligence and the capacity to act efficiently. Furthermore, to consider agents as competent humans evaluate their efficiency. Infants expect agents to act in an efficient manner (Gergely & Csibra, 2003; Jara-Ettinger et al., 2015). Fourteen-month-old infants already expect other agents to prefer more efficient individuals when selecting their social partners (Colomer, Bas & Sebastian-Galles, submitted.). Nevertheless, it is still unknown if infants expect leaders to be efficient.

In order to establish the exchange of benefits between leaders and followers, it is fundamental that leaders share the profits of their successful (and competent) actions. Therefore, leaders are not only chosen for their competence but also for their "fair attitude" (Price & Van Vugt, 2014). Several studies have tested infants' naive expectancy towards egalitarian distributions as well as infants' expectation of third-party preferences towards "fair individuals" (Geraci & Surian, 2011; Hamlin, 2013). It might be that infants expect leaders to distribute resources in an equal fashion (an outcome considered “fair” in this context).

Infants infer an agent's social power on the basis of the size of this agent's group (Pun et al., 2016). Similarly, one of the most reliable strategies to select who to follow is to rely on social information and to choose leaders that have the largest followership. In this manner, one does not need to be present when other agents demonstrate their leadership capacities and their successes (Gil-White & Henrich, 2001). Despite it has been shown that children are biased to learn and follow those who get more attention by others (Chudek et al., 2012), no one addressed this type of bias during infancy.

To summarize, we suggest that future studies should test whether infants expect leadership roles to be associated with agents' physical fitness, their competence derived from efficient actions, their fair attitude in distribution tasks and their prestige inferred by the number of followers they have. All those studies will shed light on the early representation of leader-follower relationships, helping to differentiate between naive capacities to deal with this type of social relationships and the learned during the development through the interaction with others.

d. Conclusions and last remarks

Humans are social learners and as such they benefit from others in learning situations (Wood et al., 2013). It is adaptive to learn from individuals who interact better with their environment (high-rank agents) (Chudek et al., 2012). To access the knowledge possessed by high-rank agents, low rank agents freely confer power to the high-rank ones (Cheng et al., 2013a; Price & Van Vugt, 2014). From the previous, one can conclude that social learning and social hierarchies influence each other. In the present dissertation we have tried to provide evidence on the origin of such interaction.

Previous studies already showed that humans are biased to learn from high-rank models around the third year of life (Bernard et al., 2016; Castelain et al., 2016; Chudek et al., 2012; Fusaro & Harris, 2008; McGuigan, 2013). However, the capacity to represent social hierarchies emerges earlier in development, that is, during the second year of life (Mascaro & Csibra, 2012; Pun et al., 2016; Thomsen et al., 2011). Our results showed that infants are biased to high-rank' teachings as soon as they are able to represent agents' social status even in the absence of physical dominance (studies 1 and 4). When trying to justify the reasons underlying this bias on the basis of the influence that high-rank agents exert on others' behavior, we realized there were no published studies on infants' representation of this type of social hierarchies. For this reason, we performed a study investigating infants' representation of leader-follower relationships (study 2) and we investigated how this representation is linked with the infants' representation of social hierarchies regulating agonistic contexts (study 3). Taken together, the dissertation provides relevant evidence uncovering that infants' representation of social hierarchies is very sophisticated. We have also integrated the results in a theoretical framework accounting why infants are biased to learn from high-rank individuals.

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