INFANTS' EARLY UNDERSTANDING OF COOPERATION

An investigation into the cognitive prerequisites that guide resource distribution, agent individuation and prosocial motivation

By

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Declaration of Authorship

I hereby declare that this submission is my own work and to the best of my knowledge it contains no materials previously published or written by another person, or which have been accepted for the award of any other degree or diploma at Central European University or any other educational institution, except where due acknowledgement is made in the form of bibliographical reference.

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Author Contributions:

L. Vorobyova, A. Curioni and K. Begus developed the study concept and designed the task. L. Vorobyova created the stimuli, wrote the script for the experiment and collected the data. L. Vorobyova and A. Curioni analyzed the data. All the authors interpreted the data, worked on the manuscript and approved the final manuscript for submission.

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Abstract

Humans frequently and preferentially engage in cooperative activities across a broad variety of domains and the scope and complexity of human cooperation is unparalleled in any other species. Most cooperative activities in humans are characterized by a set of key properties, including mutual action coordination, sharing jointly obtained resources, partner choice, and a general motivation to cooperate.

In the present work we investigate the ontogenetic origins of humans' cooperative abilities. We propose that already young infants possess an evolved sensitivity to the key properties of collaborative joint activities, which can be experimentally demonstrated when they observe cooperative interactions from a third-party point of view. In our studies we show that young infants can, indeed, recognize and represent cooperative goal-directed interactions observed and draw inferences about the expectable behaviours of collaborating individuals, even before the infants themselves are able to actively engage in complex cooperative interactions with others.

In particular, Chapter 2 explores infants' expectations about resource distribution of jointly obtained food resources - food sharing following cooperative hunting - and demonstrates their ability to distinguish patterns of cooperative chasing from non-cooperative competitive or individual chasing of a prey. Our results suggest that 13-month-old infants expect agents who cooperated to obtain food to share it, while holding the opposite expectation (no sharing) for agents who were competing to catch the prey.

In chapter 3 we propose and explore the hypothesis that tracking and feature-based encoding of the identity of individual agents are promoted and facilitated by engagement in cooperative social interactions (in contrast to individual or non-cooperative contexts). We demonstrate this in a change-blindness paradigm where 13-month-old infants are shown to successfully detect a change of featural identity of a cooperative agent (following its temporary occlusion) as a function of having observed the agent engage in a joint cooperative chasing action. No such feature-based re-identification was found, however, following individual chasing actions and other control conditions. We argue, therefore, that infants' early ability to selectively encode the identity of a particular cooperative agent is beneficial for tracking the record of potential cooperative partners to aid future partner choice.

Finally, in Chapter 4 we explore the ontogenetic emergence of the basic motivational disposition of humans to engage in cooperation. We report a violation-of-expectation looking time study which demonstrates that 13-month-old infants expect other agents to prefer to achieve their individual goals by acting together with another agent rather than acting on their own (when given the choice), even when acting together to obtain the goal is more costly than acting individually. This suggests that infants ascribe additional reward value to cooperative actions that goes beyond the observable instrumental utility of those actions.

Together, the findings the studies reported suggest that by the age of 14 months infants are equipped with an ability to generate domain-specific inferences about agents' expectable behaviours in cooperative contexts, as well as showing a basic motivation to engage in cooperative interactions with social partners even when such interactions do not yield immediate benefits.

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I dedicate this dissertation to my mother Irina.

Look Ma, no hands.

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Chapter 1. General Introduction

Humans are a fundamentally social and cooperative species. While cooperation itself is not unique to humans and some forms of helping and cooperation with conspecifics are present in many other species as well, complex and mutual forms of prosocial behaviours tend to be quite rare in non-human species, where they appear only in a narrow range of specific contexts, and are most of the time restricted to interactions among kin only.

In contrast, human cooperation is distinctive in that humans exhibit a generalized ability, propensity and spontaneous inclination to readily and frequently engage in cooperative ventures in a broad variety of social contexts and with a wide range of conspecific agents in their social group. Cooperation appears to be a basic social cognitive adaptation in humans driven by a dedicated motivational system that results in complex forms of cooperative ventures in which kin as well as non-kin social partners participate. It is observable universally and in a wide variety of contexts and societies. Humans readily cooperate with people they do not really know, in many different unfamiliar situations and even in one-shot settings.

We plan to elaborate on a theoretical framework that accounts for the origins and nature of humans' cooperative abilities and provide empirical evidence from early ontogeny in support of our proposal in the following chapters. Our main objective is to experimentally investigate whether humans' evolved cognitive and motivational adaptations for social cooperation and prosocial actions are already present in early development. In particular, we shall seek answer to the question whether human infants are endowed with a specialized sensitivity to recognize, interpret, and evaluate cooperative actions (and agents performing such actions) even before they are able to actively engage in complex cooperation themselves.

Our studies aim to explore whether humans' evolutionary preparedness to recognize cooperative interactions among social agents to achieve shared goals allows young infants to draw domain-specific inferences about their expectable future behaviour. We argue that infants' hypothesized competence to draw such domain-specific inferences early on in ontogeny is a highly adaptive core part of their evolutionary competence that prepares them to engage in and learn about a broad variety of social, cognitive, and normative skills that characterize adaptive forms of cooperation. The early presence of this interpretive competence even before infants are mature enough to actively engage in and collect first-person experience with complex cooperative interactions provides the developmental foundations for becoming expert cooperative agents who are well adapted to be active participants of the social world of cooperative ventures that characterize human societies.

We base our hypothesis on multiple lines of previous research. First, we describe the experimental evidence from economic games demonstrating the degree of cooperativeness between humans, which contradicts the predictions of traditional economic models that consider humans as profit-maximising individual agents. We then discuss the standard approaches that have been proposed to explain altruistic behaviours in humans, and consider the limitations of their predictive power and ability to account for the phenomena demonstrated within the scope of the present research.

We then examine an alternative hypothesis about the evolutionary origins of cooperative behaviours. According to this proposal complex forms of social cooperation may have first evolved in the narrow domain of food acquisition under the selective pressure favouring larger returns provided by cooperative social strategies for obtaining high value food resources, such as cooperative hunting. Practices of cooperative hunting and foraging that are universally present in traditional hunter-gatherer societies even today may have been the core evolutionary domain that is likely to have shaped various unique aspects of human social cognition. These have consequently affected other domains and became generalized to deal with a variety of evolutionary challenges beyond food acquisition, leading to a generalized human prosocial disposition to cooperate in tightly knit social groups.

We then proceed to identify several foundational components of humans' species-unique adaptations for complex forms of social cooperation. These key components include coordination of joint actions and distribution of complementary roles, active resource sharing, partner selection based on investment tracking, and a basic motivation to act together. We summarize the body of available anthropological, ethnographical and cross-cultural evidence demonstrating the manifestation of these key components of social cooperation, concentrating on the evolutionarily significant and universal example of human cooperative hunting practices in traditional societies.

Further, we turn to the comparative literature and discuss to what degree these key aspects of cooperation are represented in other species', and their cooperative hunting practices in particular. We consider which core components of cooperative activities are present in other species and how they are represented, searching of commonalities as well as differences when compared to humans.

Finally, we explore the available experimental evidence for the early emergence and development of the key components of cooperation. The findings we review in this section will provide a starting point for our research. We develop arguments for the hypothesis that humans' propensity and preparedness to cooperate is adaptively supported by the early ontogenetic emergence of the evolved domain-specific inferential repertoire available already at a young age in human infants. We then identify the missing pieces of evidence to support our particular hypotheses which the present research will attempt to provide.

1.1. Resource distribution and fairness: evidence from economic games

One kind of evidence demonstrating how cooperative humans are come from studies using various paradigms of economic games. In such experimental settings peoples' behaviour strikingly contradicts the expectations that would be predicted by the standard economic theory of maximising benefits to the self. Take for example the Dictator and Ultimatum games (Camerer, 2003; Fehr et al, 2006) which indicate that participants tend to spontaneously share some money with others instead of simply maximizing their own gain.

In the Dictator game one participant – the Dictator - is given a specific amount of money and is asked to allocate it between himself and the other participant by offering some of the money to the other to keep. The Dictator is free to keep all the money or share it with the other participant – the Receiver – as he likes by offering him whatever proportion of the money he decides to give him, without any consequences or danger of retaliation. Importantly, this interaction is anonymous, participants interact only indirectly and never meet each other. In the extended version - the Ultimatum Game - the Receiver has the option to either accept the proposed amount, and then both of the participants can keep their share, or he can reject the proposal, in which case neither of them receives any money.

In contrast to what traditional economic theories would predict, people tend to offer some of the money to share it with the Recipient and do not 'rationally' maximise their own gain by keeping it all even under the circumstances where they would risk nothing (Dictator game): the mean allocation is still about 20%, not zero (Forsythe et al, 1994). Similarly, in the Ultimatum game, where the Proposer would be expected to maximize his gain by giving as little as possible, participants often give about half of the resources to the partner. In most of the replications of the Ultimatum game the median share that the Proposers offer is 40-50% (Camerer, 2003). Also, from the point of view of rationalizing one's gain, the Receiver would be expected to accept any amount of money he is offered, however, small that is (as it is still more than nothing). Nevertheless, participants tend to reject offers they deem "unfair" and prefer to leave empty handed (thereby, however, blocking the unfair Proposer from keeping any of the money) (Gueth and van Damme, 1998; Levitt and J. List, 2007).

These findings have held up across multiple replications (Camerer, 2003; Fehr et al, 2006) and across different cultures (Henrich et al, 2005, 2010) indicating that they are not simply reflecting a feature of Western societies. In a representative study, Henrich, Fehr and the colleagues (2001) tested these games in a broad variety of societies, including foragers, agricultural and modern industrialised societies. Across the board range of cultures tested the results were found to be remarkably similar: people were everywhere more generous than the standard theory of humans as 'rational economic agents' would have predicted. When explicitly questioned about why they didn't keep more money for themselves, people generally justified their behaviour by referring to fairness, saying "it wouldn't be fair".

In sum, the economic games literature provides converging evidence that strongly suggests that humans possess a universal sensitivity and inclination for fairness and a normative expectation for equal distribution of available resources.

1.2 Models of cooperation: How has cooperative behaviour evolved and stabilized?

One of the most difficult question for evolutionary theory that the widespread and universal presence of complex prosocial behaviours in human societies raises is how the propensity for cooperation has evolved and stabilized during human evolution. In common ventures where everyone contributes their individual efforts and receive their respective benefits, more selfish individuals would obtain more benefits, and therefore gain a fitness advantage. This would result in a higher likelihood that selfish individuals would propagate their genes and as a result selfish behaviour would be more likely to spread in the population, which would eventually lead to the extinction of cooperative behavioural inclinations. So how could our strong preference for cooperation emerge and stabilize across generations at all?

Below we consider several accounts that have been proposed to solve this apparent paradox by identifying fitness advancing properties that could explain the evolutionary emergence and maintenance of human cooperation. These include models of kin selection, reciprocal altruism, costly signaling, group selection, and partner choice. Each model specifies how an agent can increase its fitness by engaging in cooperative behaviours.

First, we briefly outline these models, discuss their limitations and identify the scope of their applicability. After introducing the models, we briefly explore and compare how they flare with the currently available research findings: Based on this analysis we generate specific hypotheses to clarify unresolved issues that we aim to test in the experiments to be reported in the upcoming chapters of this dissertation.

A highly influential model to explain the evolution of cooperation was proposed by Hamilton (1963) who developed notions of **kin selection** and **inclusive fitness**. He suggested that an altruistic trait could be selected for if altruistic behaviour were selectively applied to kin with whom an organism shares its genes. Even if prosocial behaviour reduces the fitness of the individual, it increases the fitness of the individuals genetically related to him (his kin) therefore increasing the overall likelihood that the altruistic trait would propagate in the population. Hence altruistic behaviour, induced by positive social emotions towards one's kin, could have been easily selected for. Indeed, a large part of human prosocial behaviours can be accounted for by nepotistic altruism, as humans are more likely to show all kinds of prosocial behaviours including sharing, nurturing, and protecting towards their relatives than towards non-related individuals (Pinker, 2015).

However, Hamilton's proposal could not account for non-kin cooperation. Trivers (1971) suggested another mechanism that could fill this gap: **reciprocal altruism**. The idea behind this model is that an individual might temporarily reduce her fitness in the present in favour of another, even unrelated individual in order to increase her fitness in the future. This relies on the notion that the receiver of the present benefit is likely to return the favour to the altruistic donor in the future. The mutually beneficial trading of favours brings benefits to all parties, at least for as long as no one defects and exploits their partner. As in the case with nepotistic altruism, the model of reciprocal altruism can explain a lot of aspects of human sociality, e.g. in the economic games individuals engage in cooperative behaviour because it may provide an opportunity for establishing a mutually beneficial relationship for the long-term (even if in reality sometimes these individuals may never interact again).

While in the economic game studies the identity of the players is typically hidden from each other, in reality the altruistic act and the identity of the agent performing them (as well as that of the recipient) are often in public. The theory of **costly signaling** has been proposed to explain certain phenomena that characterize altruistic behaviour, which remain difficult to account for by the previous models, in particular, *public generosity* and *distribution of food* where the providers do not control the pattern of sharing (and sometimes even unable to secure a share for themselves, see Smith & Bliege Bird, 2000). In such cases the provider cannot ensure either that the receivers (who are also the potential reciprocators) obtain their desired amount of benefit, or that the free-riders are deprived from the resource – preconditions that are necessary to stabilize the likelihood of delayed and proportional reciprocation. In the model of costly signaling these preconditions are ensured by the providers' broadcasting of costly signals towards potential mates, cooperative partners and competitors (which implies their honest fitness-related quality of prosocial attitude) This way providers broadcast their qualities that are non-transparent for direct assessment but allows for inferring them (based on the apprehended cost of their provision signals). This has important implications for the current well-being and future benefit of others who prefer to engage in the interaction with the signaler. The benefit for the signaler is ensured by being preferred as a mate or a long-time ally of reciprocators who are likely to return the predictable and secure benefit they receive from cooperating with the costly signaler repeatedly in future cooperative ventures (Smith et al, 2003).

Another prominent model of cooperation suggested by **Boyd and Richerson** (1990, 2006) claims that people tend to follow *social norms* including *aversion to unfair behaviour*. This leads to a preference for partners who act prosocially. The way to stabilize such behaviours would be achieved by the *punishment* of those individuals who don't comply with the norms (*altruistic punishment*). Formal models have shown that, indeed, cooperative behaviour could be stabilized by altruistic punishment in groups (Boyd and Richerson, 1992; 2006) resulting in survival advantage, a process that became known as **"group selection"**. As long as the returns produced by the cooperative activities are on average higher, groups that practice social norms of cooperation and punish selfish defection would yield higher welfare to its members than groups with less pervasive cooperative norms. Consequently, only groups with strong cooperative norms and individuals supporting those norms would survive, gradually spreading both cooperative norms and cooperative traits, in the process of cultural and genetic evolution.

This proposal is in line with a set of experimental evidence: people do tend to punish uncooperative partners, as in Ultimatum Games where Receivers reject offers they deem unfair in order to reduce the gains of non-cooperative players. People readily decline taking the (unfair amount of) money they were offered in order to thereby punish those who did not contribute a fair share in the past and, as a result, they reinforce the prosocial norm (Fehr and Gächter, 2002, see section 1.1)[1].

Cooperation can be stabilized in various ways. Most of the models described above are *partner control* models, in which partners interact repeatedly and can penalize each other for failing to cooperate. The partners are given and therefore cheating prevention by punishment is the only resource to stabilize cooperatives behaviour, as described by Axelrod's (1984) *tit-for-tat* strategy, where agents first cooperate and then replicate their partners' behaviour.

However, in natural circumstances it is seldom the case that an individual is "stuck" with a partner forever without having any other "outside" partner as an option to cooperate with. In *partner choice models* individuals can choose between multiple cooperative partners and have the option to switch partners when their current partner does not satisfy their expectations during their interactions.

One example of partner choice in animals is provided by the interaction between the cleaner fish and reef fish, their clients (Bshary & Grutter, 2005). The cleaner fish eats parasites from the body surface of their clients, therefore benefitting by getting a reliable source of food, while the client fish also benefits by having disturbing parasites removed from their body. However, cleaner fish actually prefer the client's mucus as food and sometimes defect from the cooperation contract by feeding on the mucus rather than the parasites. The client fish responds to such cheating by either "punishing" the cleaner (attacking and chasing it away),

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[1] There are important methodological caveats to studies on altruistic punishment, however. In various versions of the task participants punished less at their own cost, e.g. in case no one (including experimenters) knew whether the participants punished the defectors at their cost (Kurzban et al, 2007), or if the possibility of the defector to act towards the participant was removed (Krasnow et al, 2016).

Similarly, field observations confirm that even though third-party punishment is present in traditional small-scale societies, it is not very frequent (e.g. Gurven and Winking, 2008). People do engage in punishment but mostly when they were directly affected by the defection (Baumard and Lienard, 2011; Price, 2005; Wiessner, 2005). What they might do instead, however, is to note the defector's bad character and choose to interact with another, more cooperative partner (see also Chapter 3 below on agent individuation and re---identification).

or by switching partners - swimming away and finding other cleaners to do the job. By preferring good and more reliable partners client reef fish create pressure for the selection of cooperative behaviour in cleaner fish which stabilizes reciprocity.

The empirical findings reveal a complex set of criteria in humans: in experimental settings humans tend to choose the most cooperative partners available instead of those unwilling to contribute, who are gradually left out of the opportunities to cooperate (Barclay 2004; Barclay & Willer 2007). The importance of this is reflected also in the information acquisition routines that people apply. Indeed, people tend to attend to and actively search for the information that can provide cues of the cooperativeness of their partners (Kurzban & DeScioli 2008; Rockenbach & Milinski 2011), e.g. costs of their actions (Ohtsubo & Watanabe, 2008) or how spontaneous their behaviour was (Verplaetse et al. 2007). Studies on cooperation where partner choice was available have shown that in this case the cooperation can be stabilized without punishment or coercion (McAdams, 1997). Historical data also offers multiple examples of complex trade of highly valuable goods without formal binding institutions offering punishment in case of defection (e.g., medieval traders in Europe: Greif, 1993; Jewish jewellers in New York: Bernstein, 1992)). What prevents people from cheating in such cases are reputational damages, which leads to the risk of being left out of the future transactions.

Considering the complexity of humans' social life and the scale and diversity of cooperative behaviours, it is likely that all of the models are needed to account for the full range of human cooperativeness. However, for the purposes of the current research we choose to build on reciprocal altruism and partner choice models.

The focus of the present work is a type of relationship typical for human interactions with non-kin: mutualistic relationships where individuals get engaged in cooperation repeatedly, both contributing to their joint venture and expect to gain benefit from it according to their invested effort. This kind of relationship model has also been described as "equality matching" by Fiske (1992) who emphasizes that such relationships are based on reciprocity and have to be balanced (as to the amount of efforts and returns experienced by each of the individuals involved), at least on a long-term scale. We shall limit the scope of our research questions to the domain of this type of interactions; however, we shall also discuss the possibility of how other types of interactions (e.g. kin-based, such as in the parental care context) might relate to our predictions regarding to the kinds of inferences infants draw about the future behaviour of the participants.

Accordingly, the models most relevant for our currently investigated questions are *reciprocal altruism* and based on its assumptions the inferred expectations concerning future *partner choice*. We believe these models provide the best account for the available data for human cooperation with multiple partners including even strangers (section 1.1) and generate important predictions that our hypotheses are built on and that our studies aim to test.

In particular, these models account for expected patterns of resource sharing behaviour in mutualistic relationships and sharing fairly the outcomes jointly achieved in a common venture is an important factor in determining future partner choice (e.g., Aspelin 1979; Henry 1951). We explore the developmental origins of sensitivity to resource distribution in cooperative settings in Chapter 2. Furthermore, reciprocal altruism together with partner choice predict the need for tracking individual partners and welfare imbalances over time (a process for which the capacity for partner recognition is a necessary precondition). In

Chapter 3 we shall test the hypothesis that processes of feature-based agent individuation, agent tracking and re-identification is facilitated in the context of joint cooperation in infants. A general inclination of human agents to cooperate is also predicted by the models of reciprocal altruism and partner choice. In Chapter 4, therefore, we shall test whether infants attribute a joint utility value to coordinated cooperative actions observed even before they can engage in complex cooperative interactions themselves. (Note, however, that as a more general hypothesis a basic motivational preference for cooperative actions could also be predicted by group selection models and their account of the spread of cooperative traits in human communities).

1.3. Emergence of cooperation in the domain of food acquisition

Here we want to explore the proposal that human prosociality initially evolved not as a generalized ability and preference to cooperate, but as a means to solve reoccurring problems in a specific domain. One of the repeatedly encountered central problems faced by different species, including humans, is the domain of food acquisition and distribution. Cooperation may have evolved as an efficient strategy to enhance the fitness of those who had engaged in cooperative food acquisition, by producing higher returns than any of the participants could have obtained individually.

Evolution probably selected for specialized skills and cognitive competences in particular task-domains that brought about high returns but required complex and coordinated common efforts by individuals, and cooperative hunting was likely to be one of the most significant examples of such joint social activities. Our persistent reliance on meat dates back to 2 million years ago (Ferraro et al., 2013). Hunting was one of the central activities our ancestors engaged in to maintain reliable provision of meat for their social group. As the archeological evidence indicates most hunting was done in groups, as hunting for big game was too complex, difficult, and dangerous to be performed alone. There is a wide range of evidence suggesting that humans hunted for different kinds of prey, both big and small (Mithen, 1996; Potts, 1989; Stanford & Bunn, 2001). Kaplan and colleagues (2000) suggest that our increased reliance on meat created a cascade of self-sustaining loop of co-evolution between cooperation and cognitive abilities: the more meat humans ate, the larger brain they could grow, which in turn allowed them to hunt and cooperate better to get even more meat.

Some have argued that it is the long evolutionary history of cooperative hunting and food sharing where humans' tendency to cooperate with non-kin and even with strangers may have originated from (e.g. Cosmides & Tooby, 1992, Hill, 2002). Potentially, cooperative abilities have not been selected as a domain-general capacity that was applied equally to a broad variety of different domains, rather they were characterized by rich internal structure and involved domain-specific inferences. As such, cooperation might have first evolved not as a general human disposition, but as a domain-specific capacity to solve particular and reoccurring problems related to food acquisition and distribution, and it only later became a generalized trait that could be applied to various other domains as well.

Building on these suggestions, in our studies we explore the origins and early ontogenetic emergence of fitness-relevant cooperative competences in the domain of food acquisition and distribution by presenting infants with animated abstract event scenarios that represent key properties of cooperative hunting and foraging activities. We hypothesize that the domain-specific cooperative competences that have been selected during our evolutionary history, may manifest themselves early on in ontogeny enabling infants to recognize and interpret patterns of cooperative and coordinated interactions performed by two jointly acting agents to achieve a shared goal. Assuming that the structural properties of such coordinated interactions provide cues that are recognized by infants as indicative of a cooperative hunting event, such as two agents jointly chasing an escaping single agent with the shared goal of catching the ‘prey’, we hypothesize that infants would be able to draw domain-specific inferences about the expectable future behavior of the chasers after having caught the prey. In particular, we suggest and shall explore the hypothesis that recognizing cooperative chasing will allow infants to infer and expect that the prey will be shared (i.e., consumed together) by the two agents who have coordinated their efforts to achieve their shared goal and catch the prey. We hypothesize that such domain-specific inferences will be demonstrable early on in young infants even before they are capable of actively participating in such complex cooperative activities themselves.

1.4. Distinctive properties of human cooperation (in ethnographic reports)

Complex tasks such as hunting for big game is not only difficult but also risky to accomplish alone, thus, it requires the division of complementary roles and duties to be performed by the cooperating participants. The efficient and successful coordination of such collaborative goal-directed activities necessitates co-monitorting, flexible modification of behaviour, and may require mind-reading as well as communicative signaling (e.g.Tomasello et al, 2005; Tomasello, 2019).

Furthermore, such complex collaborative ventures presuppose a basic social motivation and joint commitment to act together and to adhere to shared social norms of resource distribution. Here we identify and discuss several key elements of cooperative ventures using cooperative hunting as the prime and evolutionarily significant example of complex forms of social cooperation in humans.

Cooperative hunting involves a number of fundamental and interrelated factors that go way beyond the prerequisites necessary for individual hunting (when tracking down and killing the animal prey alone). Below is a short list of the most essential features that characterize and are universally present in cooperative hunting in traditional hunter-gatherer human communities:

A. ***Coordination and complementary role structure:*** Participants have to perform different complementary roles that form interrelated subgoals that are organized in a hierarchical structure to achieve the shared final goal of the cooperating participants. The cooperating individuals also need to mutually represent the hierarchical structure of joint action plan that each partner must follow including their interrelated complementary roles. Furthermore, as the event unfolds they must actively co-monitor each others' behavioural performance in their respective roles in order to coordinate and adjust their own behaviour online based on what the other participant is doing.

> One example of how complex and demanding of a process cooperative hunting can get is provided by Australian aboriginal net hunting (Satterthwait, 1986). Net hunting was wide- spread across the continent and it was used for hunting many types of prey, including kangaroos, wallabies, dugongs, emus and dingos. The venture starts with the production of a net, which is a long and effortful process. Most of the time the net is made from plant fibers (although human and animal hair is also used), which have to be extracted, soaked, dried in the sun, beaten or rubbed (or a combination of those). Then the fiber has to be spun into a rope, assembled into a net with nodes. Once the net is

ready the hunters would carefully select the site. One of the techniques of kangaroo net hunting involves finding a suitable waterhole where kangaroos would often go to drink. Then hunters would set poles around the trail leading to it, and leave them there for several days so that the kangaroos get used to them and would not become too vigilant. Finally, on the hunting day the hunters would choose a suitable kangaroo going to the waterhole, and while it is busy drinking, set the net on the poles and hide in the bushes nearby. Once the kangaroo appears, it would be driven by the hunters into the net where it would be contained. Importantly, the individuals in the hunting group are divided into several subgroups to fulfill different complementary roles in a coordinated manner: while some of the hunters drive the animal into the net, others who are hiding nearby are dispatched to capture it when the prey has become entangled in the net and is unable to escape.

B. ***Sharing the cooperatively obtained outcome*:** After the food resource has been jointly acquired it must be distributed and shared among the participants. Normative rules that specify patterns of resource sharing must be jointly obeyed, active and fair sharing is based on (and provides the basis for) mutual trust and forms a precondition for the success of future cooperative interactions and ventures. Sharing behaviour is also one of the key determinants of future partner choice - those who do not share fairly are not chosen as partners in future cooperative ventures.

Food sharing is a quintessential feature of small-scale traditional societies. In traditional hunter-gatherer communities that rely heavily on big or hard-to-get game for their survival there are strict rules on how the prey should be distributed. One of the most common patterns is for the game to be initially distributed between the hunters as indicated by a large number of anthropological studies providing converging evidence coming from different cultures: Netsilik Eskimo (Damas 1972), Nyae Nyae !Kung (Marshall 1976), Pintupi (Myers 1988), Washo (Price 1975), Mbuti (Ichikawa 1983), Aka (Kitanishi 1996; 1998), Efe (Bailey 1991), Lamalera (Alvard 2002)). The general finding of these investigations suggest a universal pattern of resource distribution reflecting the joint consideration of several factors such as invested time, amount of labor and intent of contribution which are all important indicators of the degree of commitment and normative adherence to the social contract that underlies the complex organization of the cooperative hunting venture. These factors jointly determine the pattern of distribution when sharing the resources obtained through the cooperative activity of the participating members of the social group. The notion that "work transforms material things into property" (Barnard & Woodburn, 1988) is confirmed by ample ethnographic evidence showing that hunters initially pool the catches between them. Australian Pintupi Aborigines share the outcome of the cooperative hunt, such as the kangaroos and hare wallabies captured, among all the participants of the hunt (Myers, 1988). Similarly, the cooperative hunt of capybara among the Hiwi living in the savannahs of South America results in equal distributions between the hunters who coordinated their actions to chase the prey down (Gurven, 2004). Hunters in Ache (subtropical forest of Paraguay) and Tsimane (lowland Bolivia) go in pairs on day hunts and share the catches with their partner (Gurven, 2004).

C. ***Identity tracking and long-term representation of individual cooperative partners.*** Since the long-term success of repeated cooperative ventures in a social group is built on mutual trust and reciprocity among the cooperating individuals, it requires participants not only to monitor each others' cooperative skills, reliability, commitment and fairness in sharing, but to recognize and remember individual cooperative partners and recall their relevant characteristics (whether or not they were good, skillful, and reliable cooperators in the past) to direct and ensure adaptive choices of partners for cooperative ventures in the future.

In hunter-gatherer societies people seek and exchange information about others' relevant behaviours and reputation that pertain to their following of social norms in cooperative contexts (Wiessner, 2005) and rely on such information to direct their future social interactions and determine their choices of cooperative partners. Woodburn (1982) observed in the Hadza of Tanzania that "units are highly unstable, with individuals constantly joining and breaking away, and it is so easy to move away that one of the parties to the dispute is likely to decide to do so very soon, often without acknowledging that the dispute exists". Partners are also often chosen on the basis of their sharing behaviour (Gurven, 2004).

D. ***Basic motivation to act together.*** It is likely that humans possess an evolved preference and strong social motivation to act together to ensure participation in cooperative and prosocial activities among the individual members of the social group. Moreover, such a basic social motivation and preference for engaging in joint activities can be hypothesized to be not strictly utilitarian (i.e., being motivated to act together only when cooperation is evaluated to yield higher returns than individual action would). Rather, an inherent social preference and motivation to act together may have been selected because it promotes the acquisition of cooperative skills including specialized cognitive abilities that support mutual coordination, co-monitoring, mind-reading, and communicative exchange of relevant information with social partners.

The ethnographical evidence coming from a range of different cultures demonstrates that cooperative activities in general and cooperative hunting in particular are universal in human societies across the globe. A large portion of human cooperation is centered around obtaining and distributing resources, especially food.

The evidence we presented suggests not only that food sharing is important in many traditional societies, but it seems to substantiate the stronger conclusion that sharing collaboratively gained resources is a universal and fundamental feature of social cooperative ventures in human communities (such as the prototypical example of collaborative hunting demonstrates). Furthermore, the convergent anthropological, ethnographic, and cross-cultural evidence also supports the hypothesis that the basic and universal human disposition and social norm to share jointly obtained resources is sensitive and proportional to the perceived degree of effort contributed by the individual participants of cooperative ventures. Even though the specific rules for how exactly the rewards of joint efforts should be distributed vary among the different cultural groups, all of them show basic sensitivity to the obligation of sharing as a function of the relative investment and degree of contribution made to the common effort.

As we discussed before (see section 1.3), it has been proposed that cooperation initially evolved in the domain of food acquisition. In the experiments reported here built on this assumption by focusing on the context domain of food acquisition when investigating the key components of infants' representations of cooperative activities.

In the following sections we explore the comparative literature in order to evaluate whether, and to what degree are these basic components of cooperation present in other species as well, and how are they manifested in cooperative hunting practices. We then briefly provide a more detailed discussion of the type of cooperative behaviours present (in hunting and beyond) in our closest evolutionary relatives, chimpanzees, on the one hand, and cooperative breeders in the primate family, on the other, with whom we share many cooperative practices that are absent in other species (including apes).

1.5 Cooperative hunting and patterns of food distribution in non-human species

Cooperative hunting has been reported to exist in many species other than humans, including primates (Boesch and Boesch, 1989), carnivorans (lions: Packer et al, 1990; hyaenas: Mills, 1990; wolves: Mech, 1975) and cetaceans (Pitman and Durban, 2012). However, behaviours in social contexts that are described as cooperative in the literature vary greatly as to the degree of coordination involved between the participating individuals, the various examples ranging from passive cooperation when hunters do not intentionally interact or pay attention to each-other's action (e.g., social spiders attacking the same large prey, Ward and Enders, 1985) to more active and complex forms of intentionally coordinated actions that involve division of complementary roles and co-monitoring in collaborative activities (e.g. ambush and chasing in wild dogs, McNutt and Boggs, 1996). In general, however, the evidence available supporting forms of cooperative hunting in non-human species remains controversial. In particular, they typically lack the degree of organizational complexity and the multiple constitutive features that characterize the cooperative practices and social normative properties of cooperative hunting and norms of food sharing that are universally observed in traditional human social groups.

An essential property of cooperative hunting is that it results in a significant increase in the benefits gained by the cooperating individuals when compared to comparable gains achieved by individual hunting practices, e.g. by increasing the chances of catching the prey, capturing a larger prey, or capturing prey more effectively in comparison to when an individual hunts alone or in uncoordinated groups. Indeed, during cooperative hunting the energy costs spent are decreased and the per capita food intake is increased for the individuals involved (e.g., Rasmussen et al. 2008; Packer and Ruttan 1988).

Some simpler forms of non-human cooperation, such as *passive cooperation* (e.g., bats hunt next to each other to eavesdrop on other individuals' sonar responses in order to detect a prey, Dechmann et al. 2009), do not seem to satisfy the criteria for truly cooperative behaviour. In this example, hunters benefit from the presence of others but do not intentionally interact or mutually adjust their behaviour based on the others' actions. We will not consider further such simple forms of arguably cooperative behaviour but will turn to examining the evidence for other constitutive properties of complex cooperative hunting that have been reported to be present in some non-human species, mostly in carnivores and apes.

Division of complementary roles. Classifying cooperative hunting as collaboration (Boesch and Boesch 1989) requires division of complementary roles among participating individuals where the different individuals' behaviour is influenced by and is based on the positioning and behaviour of the other hunters and that of the prey. It has also been reported that individuals take on the same roles repeatedly over many hunts (Anderson and Franks 2001).

Take the example of cooperative hunting observed in lions (Schaller 1972; Stander 1992a, b). During a cooperative hunt a group of lions captures the prey with the help of a clearly complimentary role division: first, the *ambushers* move around to get behind the prey, while the *drivers* stay put in place being inactive. Once the ambushers took up their positions, the drivers start chasing the prey towards them while the ambushers stay hidden from the prey's view. As soon as the prey is close enough, the ambushers start chasing it in order to capture it. If one individual chaser gets grip of the prey, it is often helped by others who catch up with them and restrain the prey, helping to bring it down and kill it (Schaller 1972; Stander 1992a, b).

However, cooperation does not end here. One of the crucial elements of cooperative hunting that have been suggested to contribute to the main benefits of cooperation (MacDonald, 1983) is the increased ability of the group of hunters to defend the kill from kleptoparasites, i.e., scavengers and other predators. For example, wolves tend to consume more food when other conspecific cooperative hunters are present and they protect the carcass from ravens together (Vucetich et al, 2004).

Sharing the cooperatively obtained food resource. After the kill has been achieved in a cooperative hunt, the prey is shared among the participants. The most typical pattern of allocation is according to social status: more dominant individuals get preferential access to the resource (Bailey et al, 2012). For example, after a group of cooperating lions make a kill the first ones to feed on the prey are the adult males until they are satiated (even though they often don't participate in the hunt which is typically performed by the females). They are followed by the females and the cubs only get to feed last (who also follow their internal hierarchy).

A much rarer pattern of sharing is allocation according to need. In this scenario the prey is shared amongst all group members, including those who did not participate in the hunt, such as individuals too young to hunt or incapacitated adults. Outside human hunter-gatherer societies such pattern has been observed in killer whales (Wright et al, 2016)

Cooperation and partner choice. The animal literature does not provide evidence about any non-human species where animals would choose or change partners based on their experience with other conspecific individuals' performance during earlier cooperative hunting events or their subsequent sharing behaviour. Moreover, even though punishing for cheating is present in different species in multiple situations (Clutton-Brock and Parker 1995), there are no reports of punishment for cheating or underperforming during a hunt.

There does not seem to be selective partner choice involved in cooperative hunting in chimpanzees either: the hunt is largely opportunistic and begins once the prey is encountered by an individual chaser who is followed by other individuals who happened to be around at the time (Tomasello et al. 2005, Tomasello 2014, although see Boesch, 2005). Chimpanzees do engage in partner selection to make coalitions for conflicts or intra-group warfare. The criteria for the partner choice is social hierarchy: individuals form local partnership coalitions with the most dominant others they can find being in their proximity (Nishida & Hosaka, 1996). The basis of selection is thus dominance and the partnership setting is competition (Harcout & de Waal, 1992; Silk, 2007).

There is evidence, however, that great apes can perform partner selection for other cooperative purposes, although this has been reported only in the experimental settings. Mellis et al (2006) showed that even with little experience with different individuals chimpanzees are able to select those who will be better cooperative partners and tend to choose them to cooperate with. In another set of studies, apes either experienced the behaviour of "nice" or "mean" humans (either giving them food or disrupting them from getting it), or observed humans who were being nice or mean to another person. The results showed that in both cases apes later preferred to beg food from the nice human (Herrmann et al. 2013).

1.6 Cooperative behaviour in nonhuman primates

We will now turn in more detail to the cooperative behaviours of our closest evolutionary relative, the chimpanzees, and other primates. As discussed before, the breadth and depth of human cooperative activities as well as the variety of domains it is found in are unparalleled by any other species. However, it would be useful to identify the domains and aspects of cooperation that are present in species we share evolutionary history with in order to identify those cooperative behaviours (or particular aspects of them) that are uniquely human.

1.6.1 Cooperative hunting in apes

Wild chimpanzees frequently hunt in groups for small and medium-sized vertebrates, most commonly red colobus monkeys. However, there is an on-going controversy about whether such hunting ventures are truly cooperative in nature or not (see Boesch, 1994, 2005, vs. Tomasello et al., 2005).

A hunt typically starts by chimpanzees encountering their prey by chance during their regular activities, although there are some reports of active search for a prey (Boesch, 1994). Once an individual spots a prey (usually a colobus monkey) and starts chasing it, several other individuals who observe this join in to chase the prey. In some groups (Taï chimpanzees) there seems to be a role division among “drivers” and “blockers” (Boesch and Boesch, 1989). One chimpanzee drives the prey and other individuals surround it from different directions and don’t let it escape. According to Boesch (2005), individuals participating in the hunt have a common goal and take complimentary roles to accomplish it.

However, a different interpretation of these activities have been proposed by Tomasello and colleagues (2005) who suggest that instead of truly joint goal-directed interactions parallel but individual goal-pursuit is sufficient to explain the success. According to this account the events in the hunt unfold as follows: one individual who notices the prey starts to chase it, in the presence of other individuals nearby. The others who witness this, follow and take a position relative to the rest of the other chasers so that it gives them the best chance of catching the prey during the hunt. In this account all the chimpanzees have their individual goal of catching the (same) prey themselves.

Another indicator of a truly cooperative hunt might be the pattern of sharing of the prey among the participants after the prey has been caught and killed. The data suggests that hunters receive more meat than non-hunters (Boesch and Boesch, 1989), which, however, might simply be a consequence of the physical proximity of the hunters to the carcass. Most of the sharing that happens is passive and is induced by persistent begging: the possessor while consuming the food appears to be annoyed and experience a constant pressure exerted on him by the other individuals vocalisations and begging gestures. The possessor would often try to avoid sharing by climbing to a separate branch with the carcass to restrict access to it by others, turning its back to or actively chasing away the beggars (Gilby, 2006). Still, the possessor usually has to give up a part of the meat to the beggars, and the more active the beggars are, the more meat they get. Such pattern of sharing fits the model of tolerated scrounging, a passive mode of sharing, which suggests that the hunting venture is not truly cooperative.

Cooperation can be considered efficient if collective group hunts can produce higher returns than individual hunts. While it seems to be the case in chimpanzees' group hunting, it is likely that it is simply the consequence of more hunters being present and going after the single prey rather than being the result of truly cooperative and jointly coordinated efforts to secure a shared goal.

Nevertheless, chimpanzees' group hunting represents a complex coordination problem that requires individuals participating in the parallel hunt at the same time to take into account the position and actions of the prey, the surrounding environmental obstacles, and the relative positions, actions and goal-directed intentions of the other hunters.

1.6.2 Motivation to cooperate

Chimpanzees are also able to act in coordination with others when faced with a problem they cannot solve on their own, and they understand that they need a partner in order to do so. Melis and colleagues (2006b) demonstrated that under such circumstances chimpanzees can produce a behavior that is beneficial for another individual e.g. they would open a door to allow a conspecific to enter the room to help perform the task. They will also provide tools for another individual, who needs this tool to unlock a reward for both of them (Melis and Tomasello, 2013).

However, chimpanzees do not prefer collaboration if they can achieve their goal on their own. Rekers and colleagues (2011) presented chimpanzees and 3-year-old children with a task they could either solve on their own (such as pulling a baited board close to themselves by simultaneously pulling with their two hands the two ropes attached to the board), or by choosing to coordinate with a partner who could pull one of the ropes while they pull the other. The rewards that were obtainable by each individual - either food for chimpanzees or toys for children - were kept equal for each of the two individuals in both conditions. While children showed a strong preference for obtaining the reward by coordinating with a partner, chimpanzees chose randomly between the two options. Interestingly, chimpanzees chose randomly between the two strategies even though they achieved their reward significantly (almost twice) faster when pulling the rope with a partner, while children needed the same amount of time in both conditions.

Importantly, all the studies mentioned above were performed with adult chimpanzees. When younger chimpanzees between three to seven years of age were tested on a simple coordination task of pulling the rope together, they failed and could improve their performance only after extensive human training (Hirata, 2007).

These results suggest that while coordination skills are available to chimpanzees, they are only employed when no reward can be achieved without the participation of a partner. The evidence suggest that chimpanzees prefer to act individually to achieve their goal, and even when joint coordinated action is less costly, they don't show an inclination to act together. This contrasts with young children's apparently inherent preference and motivation to engage in collective and cooperative actions rather that choosing to act alone, as we shall discuss in the following sections (see section 1.7).

1.6.3 Cooperative behaviours in cooperative breeders

In contrast to our closest relatives, the great apes, there are other – less related – non-human species that seem to share a number of key properties of truly cooperative and prosocial behaviours that characterize humans. In particular, cooperative breeders, such as New World monkeys exhibit prosocial acts such as proactive food sharing, some forms of active teaching and allo-parental care that are typical social traits in humans but virtually non-existent in great apes (van Schaik & Burkart 2010; Hrdy, 2009; Jaeggi et al. 2010a). This is important as all traditional hunter-gatherer societies are argued to be cooperative breeders where allo-parental care of kin as well as non-kin can be universally observed. While cooperative breeding has evolved in other non-human species as well, our closest relatives, the great apes, are not among them. This suggests that hominin ancestors have evolved to be cooperative breeders only later in their evolutionary history when other human-specific features of social cooperation have also been selected (Hrdy, 2009).

The presence of a strong basic motivation to cooperate that appears to be a central evolved feature of human social groups can be tested in unilateral cooperation games, where a joint effort is required but only one of the partners is rewarded. While in chimpanzees cooperation breaks down very fast, non-humaqn cooperative breeders like tamarins persist in such a task for a long period (Cronin & Snowdon 2008). It appears that tamarins possess a basic motivation and preference to act together with other conspecifics which leads them to sustain cooperation even without any short-term benefit for the individual involved. Interestingly, capuchins, who also belong to cooperative breeders, can sustain such cooperation as well, but only in the presence of immediate reciprocation when the role of the cooperator who benefits from the joint efforts is alternated between the partners (de Waal & Berger 2000).

Based on these findings Jaeggi et al (2010a) suggest that there are three foundational components of human cooperation that can be traced to different evolutionary origins: one which is shared with other great apes, another that is typical of cooperative breeders, and the last one that is specific to humans and that has been selected together with the high degree of interdependence and long-term mutual reciprocity between members of a social group.

In sum, the above review of the comparative data available demonstrates that apes and other species are also capable to perform relatively sophisticated cooperative activities which involve some or other of the set of key components of cooperation that are jointly and universally present in human social groups. It appears, therefore, that although other animal species also engage in various simpler forms of cooperative behaviours, these do not reach the degree of complexity and breadth that characterize humans' joint cooperative activities to achieve a broad variety of shared goals, which appears to be a universal feature of all human social communities (as reviewed in section 1.5.) We shall now turn to the developmental evidence showing that many of the key aspects of human cooperation appear rather early in ontogenetic development.

1.7 Prerequisites of cooperation in human children

In the previous sections we discussed the essential constitutive properties of cooperative activities that are present in humans and reviewed evidence showing that some (but not all) of these distinctive features are also manifested by other non-human species.

We discussed that coordination and role distribution are present to some degree in felines, cetaceans and primates as well in their hunting ventures. However, other elements of cooperative activities, such as active sharing and partner choice are found rarely and only in a few species. Most importantly, however, non-human species seem to exhibit cooperative behaviour only in a number of restricted domains, unlike humans who cooperate with a large number of (kin as well as non-kin) partners and across a broad variety of different domains (as our review of the relevant anthropological, ethnographical and experimental evidence indicates).

In order to proceed with our goal to identify the key components that underlie the uniquely human propensity for cooperation, we shall now examine the relevant developmental evidence with the intention to trace the origins and early manifestations of these specialized capacities that are already present in young childhood and infancy. Due to human infants' slow and protracted motor maturation it is likely that their competence for actively participating in cooperative activities in order to achieve shared goals can emerge only in later phases of the development and only gradually in the form of initially simple or partial versions of the full-fledged cooperative behaviours that adults can engage in. Therefore, we shall also be looking for evidence that may indicate early proto-versions of these capacities that may first manifest themselves in young infants' precocious ability to recognize, interpret, and draw inferences about observed cooperative activities that are jointly performed by other agents. If early interpretive competence of this kind could be demonstrated even before infants become able to actively engage in cooperative interactions themselves, such evidence would also be informative by shedding light on the currently controversial question of whether first-person experience with actively engaging in cooperative interactions with others is a necessary precondition or not for learning about and becoming able to interpret cooperative interactions observed only from a third-person point of view (cf. Henderson and Woodward, 2011; Begus et al., 2020).

By exploring the ontogenetic origins of humans' species-unique social cooperative competences we hope to identify the dedicated mechanisms and specialized interpretive systems that have been selected for during human evolution and that provide the developmental basis that enables and facilitates young humans to become skillful and reliable participants of joint cooperative ventures in their social community by adulthood. Based on our review of the developmental and comparative evidence we aim to identify central questions that are still unanswered or remain controversial and that we intend to empirically explore in the current thesis. Following the review of the developmental literature, we shall therefore outline the series of specific empirical studies that we have planned to perform and whose results we shall report in the following chapters.

1.7.1 Infants' understanding of complementary roles and goal-hierarchies of cooperative actions

As we described in section 1.4, efficient joint achievement of a shared goal usually benefits from (or, indeed, made possible by) the joint contributions of appropriately coordinated complementary actions performed by different cooperating individuals fulfilling interrelated and complementary action roles. Importantly, in such cases the individual actions performed by each agent are in-and-of-themselves insufficient or inefficient to realize the goal pursued. Therefore, to recognize and interpret the simultaneously performed complementary actions as constituting an efficient joint approach of a shared goal, it is necessary to represent the interrelated complementary roles played by the cooperating agents and evaluate the joint efficiency of their individual actions in realizing their joint outcome, which can then be attributed as the shared goal of the cooperating individuals.

There is ample evidence that young human infants show sensitivity already during their first year to the efficiency of an individual agent's actions when attributing the achieved outcome state as the agent's goal (e.g., Gergely et al., 1995, Gergely and Csibra, 2003). In fact, such sensitivity has been demonstrated in infants as young as 3-month of age (Skerry, Carey, and Spelke, 2013), i.e. even before they are able to perform efficient goal pursuit themselves (such as reaching to grasp a goal object). However, to recognize and represent cooperative interactions as constituting a joint pursuit of a shared goal it is not sufficient to evaluate the efficiency of the individual actions of each agent separately. In fact, in order to attribute a shared goal to the joint and coordinated complementary actions performed individually by the cooperative partners presupposes a number of further representational preconditions.

First, it requires representing the interrelated and co-dependent structural organization that relates the different individual means actions performed and the complementary roles they fulfill in terms of identifying the hierarchical sub-goal – final goal structure these coordinated actions jointly realize. Second, it requires the computational ability to evaluate the joint (rather than only the individual) efficiency of the complementary actions based on the combined individual efforts invested in their coordinated performance in order to optimally realize the common goal outcome they jointly achieve. Third, this requires specialized sensitivity and preparedness to recognize the necessary mutual action coordination to be implemented through flexible and appropriate adjustment of the orchestrated individual actions by the cooperating agents in order to optimize the joint efficiency of their coordinated actions to achieve their common goal outcome. It is clear that these preconditions are necessary both for actively engaging in cooperative interactions with other agents to jointly achieve shared goals as well as for recognizing, representing, and drawing inferences about such cooperative interactions that take place between other agents observed from a third-person point of view.

Below we examine recent evidence indicating that infants, in fact, manifest such understanding rather early in development. For example, at the age of 14 months human infants already appear to comprehend the structural complexity of cooperative actions and expect their partners to take complementary roles while they are trying to jointly achieve their shared goal. Henderson and Woodward (2011) demonstrated that infants understand that the individual actions of cooperative partners are critically interrelated and realize complementary roles in achieving a shared goal outcome. In a violation-of-expectation paradigm infants were repeatedly presented with events in which two agents worked together to achieve the goal of retrieving a toy from a box. One of the agents (the "box-opener") opened a box and then the second agent (the "toy retriever") pulled out a toy from the box the first agent had opened. During the test trials infants saw the “box-opener” reaching either for the box or for the toy. The results showed that infants looked longer when the first agent reached for the box, which suggests that they interpreted the agent’s actions during familiarization by attributing her a shared final goal ("to get the toy") and not the local goal of her initial action ("to open the box”), which was only a sub-goal to enable reaching their joint final goal (“to get the toy”). These results suggest that at this age infants already understand that a series of coordinated individual actions can be related in a hierarchical goal-structure as complementary actions to achieve a shared goal where the two individual acts of the cooperating partners jointly realize their desired common outcome.

Moreover, at this age infants have also been shown to be able to compute the jointly most efficient course of action leading to a shared goal, and expect a cooperating agent to perform that action even though if the action would have been evaluated as an individual means act to the goal it would have violated the expectation of individual efficiency. This was demonstrated by Mascaro and Csibra (2014) in a violation-of-expectation looking time study in which 14-months-old infants observed two agents on two sides of a fence as they were cooperating to pass objects over from one side of the fence to the other side. Given the arrangement of a set of obstacles on both sides, the two agents had to move around in individually inefficient pathways in order to deliver the objects to their goal location in the jointly most efficient manner. Alternatively, infants saw the protagonists performing actions where their individual efforts were minimalized, but their combined effort exerted resulted in an inefficient cooperative joint action. 14-month-olds were surprised if agents chose to perform the individually efficient action alternative that minimized their own effort at the expense of lowering the degree of joint efficiency of their cooperative actions taken together. This result suggests that infants are sensitive not only to individual efficiency, but in fact are able to overcome computations of individual efficiency and understand an overarching joint goal of two agents. Only by understanding that both agents work towards one, common goal would infants be able to interpret the agents' goal-directed actions as efficient.

A recent study using fNIRS optical brain imaging methodology demonstrated that even much younger infants are able to recognize and attribute shared goals to cooperative individual actions (Begus et al, 2020). In this study, authors demonstrated that 9-month-old infants are able to interpret two agents' coordinated actions as goal-directed, even when the individual actions performed appeared not efficient when evaluated separately as an individual goal-approach. However, when the respective efforts invested by the two cooperating agents were combined and evaluated together for joint efficiency, infants could establish that the agents acted to minimize their joint effort to optimize their joint efficiency to achieve their shared goal together. This only happened if infants were presented with evidence of action coordination indicating that the outcome was a jointly pursued shared goal of both agents. This result suggests that already at 9 months of age infants are able to assign the change of state brought about jointly by the agents' coordinated actions as being the shared goal of the cooperative agents, as indicated by their differential haemodynamic response[2].

Together these findings suggest that by the age of 14 months (but probably even earlier, see Begus et al., 2020) infants are already able to attribute shared goals pursued jointly by

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[2] fNIRS methodology might be more sensitive than the VOE looking time paradigms we are using in the current studies. This might also explain why in other studies (e.g. Mascaro & Csibra, 2014) younger infants did not seem to assign and process joint goals.

cooperative agents, can represent the interrelated structure of complementary action roles realized by the different but coordinated actions of the cooperating agents to efficiently achieve their shared goal together, and apart from evaluating individual efficiency of goal-directed actions, when cued they can also compute joint efficiency based on the combined coordinated efforts invested by cooperating agents in their joint pursuit of a shared goal. Based on these results, in our experiments (using a violation-of-expectation looking time paradigm) we chose to study infants of a similar age (13- to 14-month-olds) presenting them with complex stimuli depicting various scenarios of chasing events in which two interacting agents pursue a single goal.

1.7.2. The early development of expectations about resource distribution

So far we presented evidence for human infants' early understanding and encoding of cooperative actions to jointly achieve shared goals, which involve individual agents performing coordinated but complementary action roles guided by optimizing joint efficiency of their cooperative goal-pursuit. We shall consider now a further important marker indicative of another essential key component of adult humans' fully developed competence for engaging in fair distribution of the jointly achieved resources among social partners, which is a universal characteristic present in all human societies as discussed in section 1.4. The available evidence suggest that expectations for fair resource distribution emerge early in ontogenetic development. Below we review the developmental evidence supporting this claim.

Human infants expect resources to be allocated equally by a third-party agent already at the age of 15 months. Experiments designed to test this question have usually contrasted symmetrical resource distributions (that are markers of fairness) with situations involving asymmetrical distributions. This is what Schmidt & Sommerville's (2011) study implemented using a violation-of-expectation paradigm in 15-month-olds. They presented infants with scenes depicting an actor distributing food (crackers) between two recipients behind an occluder. When the occluder was removed infants saw either a fair (equal number of crackers) or an unfair (one recipient ending up with 3 crackers, while the other only with one cracker) outcome. Infants were surprised by the unfair outcome, as indicated by their longer looking time as compared to the fair outcome. Similar results were found by other studies (Sloane et al., 2012; Sommerville et al., 2012; Meristo, Strid, & Surian, 2015), with different types (food and toys) and amounts (2 and 4 items) of resources, as well as ratios (2/0 and 3/1) of distribution. Importantly, the observed distributions also exert an influence over infant's subsequent evaluation of the distributing agents: they prefer those who has distributed equally, and they expect others to prefer them as well (Geraci and Surian, 2011). This suggests that, similarly to adults, infants use the information about an individual's observed behaviour to share fairly (or not) when evaluating and choosing which agent they prefer to affiliate with: arguably a prerequisite for partner choice (see the next section, 1.7.3).

In apparent contrast to the findings of such observational studies, in experiments investigating active resource distribution older infants and toddlers were found to be reluctant to share resources with others. Eighteen-months-olds share only some of their toys, only sometimes and mostly when encouraged to do so by an adult (Brownell et al, 2013). Rochat et al (2009) found that when given a set of resources to share with an adult, three-year-olds shared about a third of the resources, while the amount shares almost reached half by the age of five. Other studies also show that three- to four-year-old children do not divide resources equally between themselves and another person when presented with the opportunity to do so, although they do share more with the members of their group (Benenson et al., 2007; Fehr et al., 2008). Children also share more as a means to manage their reputation: e.g. when they know they are being watched and judged (Engelmann et al, 2013, 2017). It is not until they approach school age that they start to share equally reliably with strangers (Gummerum et al, 2010).

However, there might be additional factors at play as well. First, infants and toddlers share more freely with others when they do not possess the resources in advance: 18- and 24-months-olds often shared equally the toys they found together (Ulber et al, 2015).

Similarly, Hamann et al. (2011) demonstrated that 3-year-old children tend to share more if they worked together with a partner in order to obtain the resources. This suggests that at least by this age children take into account common investment of efforts when distributing resources obtained together. Interestingly, 2-year-olds did not seem to share more with their cooperative partners (neither did chimpanzees). In chapter 2 we shall report our studies in which we investigated whether differential inferences about expectable resource distribution as a function of joint goals and jointly invested efforts might already be manifested by much younger infants (at 13- to 14- months of age) when applying a third-person observational paradigm in which they exhibit their expectations about resource distribution by third-party agents and do not act themselves.

1.7.3 Evaluation of potential cooperative agents: a prerequisite for partner choice

Social evaluation and preferences for some individuals over others start to emerge early in the development. Infants can and do evaluate others based on how cooperative they are, and rely on this evaluation later when choosing between or showing preference for different individuals.

At 21 months of age children prefer to hand an object to an adult who previously provided them with a desired object rather than to another adult who did not do so (Dunfield and Kuhlmeier, 2010). This preference holds even if an adult only intended but not succeeded in giving a toy to them. Their appreciation of the intention is demonstrated further by their preference of the adult who provided a toy purposefully in contrast to an adult who provided it accidentally, despite the fact that the end state was identical: the child in both cases obtained the same desirable object.

Children base their selectivity not only on first-person interactions but also on observions of individuals interacting with others. At the age of 27 months, children are more likely to help an agent whom they had previously observed giving back a desired object to an agent, than to another agent who was not observed to do so before (Dahl et al, 2013). Olson and Spelke (2008) found that 3-year-olds direct an agent to give more resources to a doll whom they had observed to give desirable objects to others before. Moreover, children prefer a doll to give more to an agent who had previously given an object to the doll directly than to another agent who was observed earlier to give an object to a different doll, demonstrating that their evaluations and expectations of sharing behaviour is complex and differentiated.

Kenward and Dahl (2011) demonstrated that at the age of 4.5 years children distribute resources based on the agents' previous behaviour. During the study children observed an agent helping another to climb a ladder or dig a hole ("helper"), while the second agent was trying to hinder the protagonist ("hinderer"). After that children tended to distribute resources ("biscuits") in favour of the helper, and explicitly justified their choice of action by reference to the agents' previous actions.

While these experiments show that infants and children track objects and agents, however, they do not speak about the role of the experienced interaction in person encoding. Could infants encode and recall the identity of and agent and are they able to re-identify particular individuals later based, for example, on their facial features? A study by Bigelow and Birch (1999) showed that even 4- and 5-month-old infants preferred to avoid a person who did not respond contingently to their actions, even one week later. Such person-specific preference could not emerge without being able to successfully encode and retain the feature-based identity of an individual agent which would be necessary for later re-identification of the same individual.

In Chapter 3 we take on the question of the prerequisites for partner choice. In particular, we shall test the specific hypothesis that infants' early (and fragile) ability to individuate, encode and track the feature-based identity of an agent over time (and over disruptions of spatial-temporal continuity induced by temporal occlusions), which allows infants to re-identify the same individual agent later, is enhanced for individuals who have been observed to participate in collaborative interactions between cooperative social partners earlier. We predict that it would be advantageous to allocate extra processing effort for feature-based encoding and tracking agent identity over time in the context of observing agents involved in collaborative interactions to pursue shared goals with other cooperative agents. Encoding and tracking the identity of cooperative agents and the ability to re-identify them later are preconditions for establishing person-specific representations of cooperators that contain previously experienced relevant cooperative qualities, competences, and dispositional traits, such as instrumental or communicative competence skills, social dispositional traits such as commitment, reliability and trustworthiness. Therefore, the capacity to encode the personal identity and the consequent ability to re-identify cooperative agents (and the cooperation-relevant properties that was previously attributed to them) later would provide the informational basis for choosing or avoiding the person as a candidate for later cooperative partner choice to team up with for future cooperative ventures.

We argue that experience with particular agents' cooperative behaviour represents highly adaptive information to encode and retain to optimize future cooperative partner choice. Therefore, cooperative contexts are the best candidates to recruit selective attention and mobilize extra processing, monitoring, and memory resources to enable feature-based agent identification, encoding and active monitoring of individual agents and their relevant cooperative characteristics. Ability for later re-idetification and retrieval of person specific information about cooperation-relevant information (based also on communicative sources of information about reputation) is a central adaptive mechanism meant to optimize partner choice in social groups that repeatedly engage social partners in highly and mutually advantageous cooperative ventures.

1.7.4 Early presence of basic motivation to cooperate

Not only are young children able to cooperate with others, they seem to be highly motivated to do so. The evidence we present below suggests that human's propensity for cooperation is present very early in the development. Furthermore, humans appear to show a basic motivation to act together in general, even under circumstances that do not result in direct or mutual local benefit in interacting with others. We have briefly discussed the fact that such a generalized preference for social interaction appears to be human-specific and engaging in cooperation in other species seems to be conditioned on its instrumentality to result in direct and local benefits.

From 14-months of age infants start to engage in a variety of cooperative behaviours, such as helping an adult by handing them the object the adult is unsuccessfully reaching for (Warneken & Tomasello, 2007). Already by the age of 18 months, infants perform coordinated cooperative activities that require them to complement the actions of a partner to achieve a common goal (Warneken, Chen & Tomasello (2006). By 21 months, toddlers encourage their cooperative partner to re-engage the joint activity if the partner stops interacting (Warneken, Gräfenhain & Tomasello, 2012).

Rekers, Haun and Tomasello (2011) compared the behaviour of 3-year-old children and chimpanzees when facing a task in which they could obtain food by either by acting together with a conspecific, or by acting alone. Results showed that children, but not chimpanzees, prefer to coordinate and act together with a partner as opposed to obtaining food on their own. Importantly, 3-year-olds preferred to cooperate even when acting together required more effort and thus represented a less efficient alternative to achieve their goal than acting alone.

There is evidence for a basic motivation in young humans to act prosocially in other domains of activities and towards younger children as well. An interesting finding is that at 20 months as well as 3 years of age providing explicit praise or rewards for acting prosocially do not affect children’s spontaneous sharing behaviour, and sometimes even diminish it (Warneken and Tomasello, 2008; Ulber et al, 2016), which suggests that such prosocial behaviours are intrinsically motivated. Infants help others in need just as much when they are alone as when their caregiver is present and even encourage them to do so (Warneken and Tomasello, 2013a). Furthermore, infants help others even if they do not know that they themselves have been helped by the other, nor that the other has helped anyone else (Hepach et al, 2017b). This indicates that infants’ motivation to help others is a genuine and spontaneous intrinsic disposition, and not induced by the expectations of others towards them that they try to satisfy. Hepach and the colleagues (2017c, 2012) also demonstrated that pupil dilation and body posture evidence suggests that infants are as satisfied when someone else helps the person in need, as when they do it themselves, which might point to the direction that their basic prosocial disposition to help is, indeed, motivated by a generic social desire to improve others’ welfare or facilitate their goal-achievent without expecting direct reciprocal benefit in return.

These studies demonstrate that humans seem to possess some basic prosociality and concern for others, as well as motivation to act on it at a very young age. Such motivation may provide indirect benefits by providing crucial learning opportunities to develop and differentiate one’s cooperative skills, and to gain relevant experience about specific social partners that facilitate future partner choice. I chapter 4 we contribute to elaborate this line of research by experimentally testing the hypothesis that young infants expect human agents to prefer to act cooperatively together with another social agents when given choice between acting together versus choosing to act alone to achieve in both cases their individual goal.

We shall test whether a preferring to act together rather that to act on their own would be maintained even if the relative investment of effort necessary to achieve the same goal is higher when choosing to act together with another agent than it would be if the agent chose the alternative to act alone to realize the same individual goal. Such a result would suggest that the choice between acting together versus working alone for an individual benefit is not simply a function of the instrumental utility value associated with achieving one's individual goal, rather acting together can generate an independent non-instrumental social utility value that, in fact, can overcome the amount of instrumental utility in determining human agents' preference for joint versus individual goal-directed action.

1.8 The current studies

Together, the various lines of relevant literature reviewed above provide converging evidence in support of the general proposal that from early on in human ontogeny children as well as young infants already manifest the key components of our species-unique adaptation and preparedness to engage in, recognize, represent, and draw domain-specific inferences about collaborative interactions of cooperative agents to achieve their shared goal together acting in a jointly efficient manner. Our review also suggests that humans evolved a basic prosocial motivation to act together and engage in cooperative actions with social partners. Such cooperative contexts induce them to pay special attention to and invest extra processing resources to feature-based identification of particular cooperative agents, to monitor them over time and encode their demonstrated cooperative skills and cooperation-relevant social, cognitive, and motivational qualities. These processes allow for their later re-identification and recall of their cooperative skills and qualities such as their expectable commitment, reliability and trustworthiness. This represent the relevant informational basis for partner choice by other social agents determining their selection (or avoidance) of the individuals as potential partners in future cooperative ventures by members of their social group.

The main objective of our present research is to experimentally test the hypothesis that the key components of humans' evolved cognitive and motivational adaptations for social cooperation and prosocial actions can be manifested to be present already in young infants in their early and specialized sensitivity to recognize, interpret, and evaluate cooperative actions and agents even before they are able to actively engage in and acquire relevant first-person experience about complex forms of cooperation themselves.

In particular, our studies aim to explore whether infants' evolutionary preparedness to recognize and analyse cooperative interactions allow young infants to draw inferences about the expectable social behaviours by the interacting agents who have been observed to engage in cooperative joint activities to achieve shared goals. We argue that infants' hypothesized competence to draw such inferences is part of their evolutionary preparedness that allows human infants to engage in and learn about a broad variety of social and cognitive skills very early on, laying the developmental foundations for becoming expert cooperators.

We shall investigate the ontogenetic origins of humans' cooperative abilities that might manifest long before children start to engage in full-blown cooperative ventures. We propose that *there is an evolved sensitivity to the foundational components of cooperative joint ventures, and even infants who do not fully engage in such activities themselves could nevertheless show preparedness to evaluate such interactions and form specific expectations about how such events would unfold even when they observe them only from a third-party perspective.* This hypothesis is based on the assumption that cooperative abilities follow typical developmental trajectory of first manifesting themselves in the evaluation of others before fully emerging in behavioural production.

We propose that infants perform the analysis of such observed cooperative interactions relying on specialized evolved cognitive mechanisms and a domain-specific inferential repertoire accessible to them that are activated by informative input cues that the structure of social cooperative interactions provide them with. Each chapter explores the presence of a different key component of this complex cognitive system and demonstrates the availability of different inferences that these interpretive mechanisms generate.

We explore infants' representations of cooperative activities in the domain of cooperative resource acquisition, the domain it may have first evolved in. Our aim is to experimentally detect the presence of sensitivity to important aspects of cooperative interactions. We hypothesize that the early presence of such sensitivity and interpretive competence is has highly adaptive consequences for individual development by providing rich learning possibilities to facilitate the acquisition of differentiated knowledge about various domains of cooperative activities and about the variety of coordinated action skills and individual differences of cooperative dispositions that influence decisions of future partner choice.

1. **Chapter 2: Inferences about sharing joint resources induced by cooperative resource acquisition.** Chapter 2 explores infants' expectations about resource distribution of jointly obtained food resources - food sharing after cooperative hunting - and their ability to distinguish patterns of cooperative chasing from non-cooperative individual or competitive chasing of a single prey**.** Our results demonstrate that 13-month-old infants, who observed cooperating joint actions by agents who mutually coordinated their respective behavioral approach to catch the prey, inferred and expected the agents to share (consume together) the prey after it has been caught. In contrast, infants generated the opposite expectation (for no sharing) when observing a competitive chasing events performed by two agents driven by their individual goal of catching the (same) prey for themselves. We also explore whether minimal cues of coordination alone are sufficient to induce the same inferential expectation for sharing the prey even in the absence of the goal-directed cooperative joint pursuit of a shared goal during familiarization. This study aims to test whether cues of coordination (without cues of shared goal approach) may or may not be sufficient to induce expectation of resource sharing.

2. **Chapter 3: Cooperation promotes agent individuation and re-identification.** In order for long-term cooperation with non-kin - a central characteristic of humans' cooperative interactions -, there must have evolved a dedicated capacity to individuate, encode, and maintain in long-term memory the representations of particular cooperators and their relevant properties experienced in earlier cooperative ventures. Such a domain-specific bookkeeping of potential cooperative partners and their various relevant cooperative

qualities (such as good (or bad) cooperative skills, degree of expectable reliability, trustworthiness, commitment, fairness, etc.) is highly beneficial to promote and direct partner choice for future interactions serving to stabilize successful cooperative practices of the social group. In this chapter we propose and explore the hypothesis that feature-based encoding and tracking the identity of individual agents are promoted and facilitated by engagement in cooperative social interactions (in contrast to individual or competitive goal-directed contexts). We demonstrate in a change-blindness paradigm that 13-month-old infants can detect a change of an agent's featural identity after having seen the agent engaged in a cooperative chasing action but not in individual chasing and other control conditions. We argue that being able to re-identify and track the record of potential cooperative partners provide valuable information for future partner choice.

3. **Chapter 4: Demonstrating humans' basic motivation and preference to engage in cooperative activities.** For sustained cooperation to function and stabilize in a social group apart from specialized cognitive capacities it must have been beneficial to select for a dedicated motivational system that induces a general preference for acting together with social partners by making social engagement inherently rewarding for the individual. We report a looking time violation-of-expectation study which demonstrates that 13-month-old infants expect other agents to prefer to achieve their individual goals by acting together with another agent rather than acting alone (when given the choice), even when acting together to obtain the goal is more costly than acting individually. We suggest that a basic preference (and its expectation by the infant observer) to engage in cooperative activities despite their relatively higher immediate instrumental and cognitive costs might serve two main evolutionary functions: first, by frequently engaging in

cooperation, individuals gain opportunities to acquire skills and abilities necessary to become proficient and skillful cooperators and therefore do not miss out on the large benefits that cooperative activities bring about. Secondly, it allows individuals to engage in cooperative activities with a number of different partners, which allows for gathering relevant information about them as cooperative partners which can be applied to direct partner choice in future cooperative ventures.

Chapter 2. Cooperative and competitive interactions modulate expectations about resource distribution

2.1 Introduction

2.1.1 Resource sharing in humans

In the introduction we have explored the hypothesis that human infants may possess evolved sensitivity to basic characteristics of cooperative interactions. This cognitive adaptation would enable them to recognize and represent collaborative joint actions and predict agents' likely actions in a variety of cooperative contexts. Such sensitivity might be manifested in young infants' interpretive competence very early in life, preceding their ability to actively engage in complex cooperative interactions. By observing and recognizing cooperative patterns of interactions between third-party agents in relevant social contexts, infants may learn about various aspects of coordinative skills and expectable behavioral outcomes that they will be able to rely on later when becoming able to actively engage in complex cooperative interactions themselves.

In this chapter we shall investigate the theoretical arguments that form the foundation of this proposal and test its predictions. First, we shall review the empirical evidence from developmental psychology and comparative research that provide converging support for the proposal that sensitivity to resource distribution is a human specific cognitive adaptation present early in life. Second, backed up by evolutionary arguments about the origins of sensitivity to fairness we shall identify the basic principles that guide human cooperation and sharing. Finally, we shall test our hypothesis about the ontogenetic origins of expectations about resource acquisition and distribution in 13-months-old infants assuming that at this age they still largely lack relevant first-person experience that could be derived from actively participating in such social interactions themselves.

2.1.2 Sharing behaviour in infants and toddlers

If during their evolutionary past our human ancestors developed and transmitted highly adaptive cooperative foraging skills and resource sharing practices, this may have resulted in the selection of specialized cognitive adaptations to recognize, evaluate, and motivate participation in cooperative social interactions and joint collaborative ventures to achieve shared goals that provide mutual benefits for the partners. Similarly, specialized psychological mechanisms may have been selected to ensure sensitivity to social norms governing the distribution of the shared resources obtained collaboratively (as a function of the relative costs incurred by the participating individuals). Assuming the selection of such species-charateristic social cognitive adaptations supporting collaborative social interactions, it can be hypothesized that the early ontogenetic onset of sensitivity to recognize and learn about cooperative activities and social norms of resource distribution could have also been selected due to their adaptive role in increasing the likelihood of survival of human social groups. This predicts that such dedicated psychological mechanisms can be expected to be active and accessible already in early ontogeny and could be manifested even before infants are able to actively participate in joint cooperative activities themselves (e.g., Tomasello & Gonzales - Cabrera, 2017, Herrmann, et al., 2007).

We have already discussed ethnographical evidence about food sharing and complying with social norms of resource distribution in traditional societies (section 1.4; for a review, see Gurven, 2004) concluding that they are likely to be universal.

Another source of evidence suggesting that sensitivity to resource distribution is a central social cognitive adaptation in humans comes from studies exploring the availability of these concepts in early development.

As already discussed in General Introduction (section 1.7.2), infants show sensitivity to fair resource distribution and expect resources to be allocated equally by third parties already at the age of 15 months (e.g. Schmidt & Sommerville, 2011; Sloane et al., 2012; Sommerville et al, 2013). However, even later in the development (18 months), they are reluctant to share their toys themselves (Brownell et al, 2013), possibly because their natural prosociality comes into conflict with the desire to possess resources themselves. Voluntary sharing slowly increases with time, and by the age of 5 children share about a half of the resources they are given with an adult (Rochat et al, 2009). That, however changes once children do not have to give up what is already in their possession but rather distribute newly found resources with another child (Ulber et al, 2015).

To sum up, findings about early sharing behaviour suggest that infants show expectations of fair resource distribution from early on, but their judgements come before their ability to act on them. We find early sensitivity and preparedness for fair resource distribution, but infants' own behaviour and tendencies to share fairly comes later on, and depends on particular circumstances (such as whether they were already in the possession of the resources). The underlying sense of fairness that guides expectations about sharing behaviour is likely to be uniquely human, and start to show itself early in the development.

In this chapter we will explore infants' expectations about a particular case of resource sharing, namely the distribution of cooperatively acquired resources. If humans' tendency to share valuable resources originates from evolutionarily significant cooperative joint activities such as collaborative hunting and foraging, it is possible that even young children would show a tendency to share resources equally if the resource distribution takes place in a context (and as a result) of joint cooperative actions performed to achieve shared goal outcomes.

Warneken et al. (2011) performed a series of experiments to study this question. 3-year-olds had to pull a platform with resources on top of it. In order to access it, children had to pull two end of a rope connected to the platform. The resources on the platform were laid out either in two or one piles, in the latter case children had to perform the division themselves. They were able to successfully do so, often dividing the resources equally. A similar study with chimpanzees (Melis et al., 2006b) showed that collaboration often fell apart if the food was in one pile, in which case a more dominant individual took all the resources, demotivating the partner to interact further.

In another study, Hamann et al. (2011) presented pairs of two- and three-year-old children (and pairs of chimpanzees) with a similar problem of resource allocation. One of the participants had control over more than a half of the resources (toys) which he could either share with the other participant or keep them for himself. However, in different conditions the resources could either be the result of common effort (cooperative condition), individual effort (parallel-work condition), or come as a windfall (no-work condition).

While the different experimental conditions did not evoke differential sharing in two-year-olds, three-year-olds shared more often in the "collaborative" condition: when ending up with three toys they proactively gave one toy to the other child significantly more often than in the "no-work" or parallel-work condition. These results suggest that three-year-old are already differentially sensitive to joint collaborative efforts when distributing shared resource outcomes.

Chimpanzees were presented with the same resource allocation problems, but unlike children, the apes' willingness to share did not vary as a function of the presence or absence of cooperation in obtaining the resources. In fact, their sharing rate was very low in general (e.g. the lucky chimpanzees gave up the food voluntarily by letting the other one to take it only in 4% of the cases).

These results suggest that toddlers are sensitive to whether the resources have been obtained as a result of a cooperative activity, in which case children actively share the rewards with their partner. Such sensitivity resulting in active sharing appears to be human-specific and can be very rarely observed in chimpanzees, who seem not to modify their sharing behaviour based on whether the rewards obtained have been the results of collaborative efforts or not (however, see Engelmann et al, 2015, who found that chimpanzees shared food that was obtained at no cost to themselves in 32% of cases with a partner whom they trusted).

These findings suggest that expectation of resource sharing as a function of collaborative effort is a likely candidate for an evolved sensitivity in this domain and it may be present early in ontogeny. Common effort implies resource sharing. But are these normative expectations available to infants even before they have cooperative interventions in their behavioural repertoire? In this chapter we are testing this possibility experimentally.

2.1.3 Principles that guide resource sharing: an evolutionary account

What are the guiding principles that regulate the sharing of resources, especially if they were achieved as a result of joint collaborative effort? Already in the evolutionary past of our ancestors many of the most beneficial human activities required joint efforts of more than one individual to secure the desired outcome. In order to participate in such cooperative activities to secure shared outcomes it is not sufficient that the collaborative venture should be i.) highly and mutually beneficial for the cooperating partners, as in addition participation also crucially depends on ii.) whether one is chosen and accepted as a cooperative partner by the social group. Baumard, André and Sperber (2013) proposed that the human disposition to share developed as a result of the selective pressure for such *collaborative partner choice*. The choice of a particular agent as a cooperative partner is based on and influenced by the other participants' experience, evaluation, representation and long-term memory for particular individual agents' degree of competence, trustworthiness, commitment, and reliability that they have exhibited during earlier cooperative interactions. In such a social environmental niche the best strategy for an individual to ensure being chosen to participate in new cooperative ventures is to prove to be a "good" and reliable cooperative partner across various and repeated collaborative interactions with other members of the social group.

One central feature that contributes to the social reputation of an individual agent being a good cooperative partner to be chosen is the propensity to share not only the costs but also the benefits of the cooperative activity. Those who do not comply with norms of fair resource distribution will be gradually excluded from the mutually beneficial cooperative exchanges as cooperating with them fails to be beneficial for their partners. As a result, incompetent, unreliable, or unfair partners would not be chosen to participate in future cooperative enterprises by the members of the group.

This evolutionary proposal is supported both by the ethnological data and experimental evidence. In many traditional hunter-gatherer societies the choice of cooperative partners is strongly influenced by an individual’s history of sharing behavior cumulated during past interactive ventures (e.g. Wiessner, 2005, Woodburn, 1982). This is convergent with the results of experimental studies showing that human adults tend to choose the most cooperative individuals as partners for future collaborative goals, while those who have previously contributed less than average are left out of future transactions in the long-run (e.g., Barclay 2004; 2006; Rockenbach & Milinski 2011; Sylwester & Roberts 2010).

This model predicts not only that partners engaging in cooperation to achieve shared resource outcomes should distribute the gained resources equally among each another, but also that the benefit received by the individuals participating in such cooperative ventures should be proportional to their invested effort. Such a sophisticated sensitivity to distributive fairness is a highly adaptive feature that is likely to become selected in a relatively stable social environmental niche in which a group of individuals repeatedly engage in various cooperative interactions to achieve shared benefits that are mutually adaptive to them and foster the survival of the social group. Such circumstances provide for opportunities to select and recruit alternative partners for a current cooperative interaction based on experience with their previous performance during earlier cooperative interactions they were involved in, and the relative benefits gained from those interactions. Chiang (2008) shows in simulations how fairness spontaneously emerges in a group if partner choice is available, even in circumstances when partner control (availability of punishment) predicts the opposite. If the benefit anticipated from cooperating with a potential partner is lower than the average benefit gained when interacting with other partners during earlier cooperative ventures, then the cooperators are better off exiting the interaction with this particular individual, or not engaging in cooperation with him in the first place (André & Baumard, 2011).

The theory of cooperative partner choice, therefore, proposes that mutually advantageous repeated interactions among individuals were favoured and selected for by evolution, and were sustained at the individual level by dedicated psychological mechanisms. These cognitive adaptations involved a sense of and sensitivity to fairness in socially distributing rewards (as a function of relative costs invested) and dedicated mechanisms to monitor and represent in memory individual social agents in terms of their previously exhibited relevant cooperative skills and enduring traits (such as their degree of competence, commitment, trustworthiness, and distributive fairness). The basic evolutionary adaptation that could lead to and maintain fairness-based behaviour in social agents is cooperative partner choice. Such partner selection adaptation can evolve in stable social environments that provide repeated opportunities to engage in multiple interactions with different partners in various cooperative ventures that provide mutual benefits.

Building on this theoretical framework, we assume that humans possess an evolved cognitive adaptation to recognize and categorize goal-directed social interactions as *cooperative* as opposed to other types of interactions, in particular, *competitive*, and a corresponding inferential repertoire that guides the expectations about the appropriate patterns of resource distribution. We hypothesize that young infants who themselves are not yet able to actively engage in cooperative activities leading to resource sharing behaviours may nevertheless already possess and exhibit such specialized cognitive adaptations in identifying and interpreting cooperative interactions, individuating, tracking and representing particular cooperative agents, and forming expectations about resource sharing.

Therefore, in the infant studies to be presented below our general aim is to demonstrate that humans' sensitivity for cooperation is already present at an early age influencing young infants' differential interpretation and selective inferences about different types of social interactions that they observe from a third-person point of view. In the first series of studies our primary goal is to test whether young infants are sensitive to behavioral cues that accompany cooperative and competitive interactions and whether categorizing goal-directed social interactions as cooperative or competitive induces them to form differential expectations about the participants' likely future interactions (especially with regard to resource sharing).

2.2. The current studies

We hypothesize that young infants may rely on specialized cognitive mechanisms enabling them to recognize patterns of cooperative *versus* competitive interactions of goal-pursuing agents observed from a 3rd-person point of view. We aim to test whether infants can identify behavioral cues indicative of cooperation (e.g. patterns of action coordination between agents in relation to a shared goal they jointly pursue). Furthermore, we also hypothesize that categorizing the interaction as a joint collaborative pursuit of a shared goal will induce in infants the inference and expectation that the achieved outcome will be shared among the collaborating partners.

The counterpart of coordination, competition is equally interesting. We assume that infants will also show special sensitivity to behavioral cues indicative of *competition* that will allow them to differentiate collaborative joint actions to achieve a shared goal from competitive interactions. In competitive interactions the rivals aim to achieve the same goal object which they both pursue as their individual goal. We suggest that identifying social interactions as competitive will induce in infants the expectation that the agent who first achieves the goal *will not share the resource* with the competing other agent.

We operationalized our hypotheses by presenting two groups of infants with animations of chasing events involving three agents: two chasers and one chasee, the “prey”. Chasing events are well suited for implementing *cooperative and competitive* scenarios because they can provide a set of cues that makes these scenes easy to identify. Infants differential reaction to the equal or unequal resource distribution (e.g. sharing or not sharing the “prey”) performed after such scenarios shall provide the evidence.

For all our studies we employed the violation-of-expectation looking time paradigm, which allows to detect infants’ expectations by comparing the relative duration of looking induced by the respective test event outcomes. We chose to study 13- to 14-month-old infants as previous research have demonstrated that by this age infants can track multiple agents and their actions (e.g. Kuhlmeier et al., 2003) and also show evidence of understanding some key aspects of joint cooperative goal-pursuit such as joint efficiency (Mascaro & Csibra, 2014) and complementarity of actions (Henderson & Woodwards, 2011).

Chasing events capture evolutionarily representative predator-prey interactions where the two kinds of goal-pursuit (cooperative versus competitive) involving multiple chasers can naturally occur. Earlier violation-of-expectation paradigms provided ample evidence about young infants' early sensitivity to efficient chasing actions of an agent in pursuit to catch a fleeing 'prey' (e.g., Csibra et al., 2003; Gao, Newman, and Scholl (2009); Yin & Csibra, 2015). Frankenhuis et al. (2013) identified a set of *specific perceptual cues* that are responsible for inducing the representation of an agent's goal directed actions as chasing, including acceleration toward an evader, changing direction (turning) and "heat-seeking" (shortening the distance between a chaser and an evader in an efficient manner).

Our main aim was to test whether infants are able to distinguish cooperative interactions from other types of interactions, and whether categorizing certain interactions as collaborative would modulate their expectations about the distribution of the outcomes obtained. To achieve this we familiarized one group of infants with animated displays of cooperative chasing interactions between two agents who coordinated their actions in jointly pursuing an animated escaping 'prey' as their shared goal (Cooperative condition). We contrasted this with another condition in which a different group of infants were familiarized with displays of two agents' simultaneously performed goal-directed but competitive chasing actions who invested their individual efforts to capture the same animated target 'prey' for themselves as their own individual goal (Competitive condition).

We used different behavioural and interactive cues that we hypothesized to be indicative of the competitive or cooperative intent of the chasers in order to induce in the infants the attribution of either individual or joint goal-pursuit to the chasers.

According to Bratman (1992), joint cooperative activities have three essential characteristics that distinguish them from social interactions in general: i) the interactants are responsive to each other; ii.) there is a shared goal; each participant has the goal that they do X together, and all participants are aware of this mutual knowledge; iii.) the participants coordinate their plans of action and intentions and so can at least potentially help the other with his role if needed.

To capture these characteristics, in our “cooperative chasing” events we presented two chasing agents who coordinated their actions, modified their behaviors to make them jointly efficient, i. e., to increase to chance that their shared goal will be achieved given the particular constraints of the situation. For example, when necessary they waited for each other to enable them to act simultaneously towards the chasee if that appeared to increase the likelihood of catching their prey in the given situation. They also exhibited behavioral signals indicative of communicative information exchange – such as turn-taking contingent reactivity (Tauzin and Gergely, 2018, 2019) - in ambiguous situational contexts where they had to negotiate a joint decision about what further coordinated but complementary actions each cooperative partner should follow to optimize their joint goal-pursuit.

In contrast, in the “competitive chasing” event no cues of cooperation were present. Instead, there were behavioural cues indicative of individual chasing (Frankenhuis et al., 2013) that established catching the chasee as the individual goal pursued independently by both chasers. Furthermore, building on evidence demonstrating infants’ early sensitivity to cues of hindering (Kuhlmeier et al, 2003) we also presented behavioral cues of hindering the other chasee in it’s goal-pursuit, thereby decreasing the likelihood that the other agent would catch the chasee before the hindering agent could.

Both types of interactive chasing events involved two parts: a familiarization phase presenting an interactive chasing episode (that involved either cooperative or competitive chasing) and a test phase presenting two outcomes of goal completion: catching the prey by one participant but distributing it equally between the two chasers (sharing) or catching the prey by one participant and consuming it alone (not sharing). In both the Cooperative Chase and Competitive Chase conditions infants saw the same test events. The test phase was arranged so that one of the two chasers always arrived at and captured the chasee before the other chaser got there. Both groups observed two test outcomes in which the agent who first caught the 'prey' either shared it with the other agent (waiting for the other to get there and then 'eating up' the prey together) or did not share (but consumed it alone by the time the othert agent got there). Registering infants' relative looking times during observing the alternative test outcomes provided a measure of violation-of-expectation that could be used to test whether they expected different resource distribution of the benefits obtained as a function of having seen a cooperative versus competitive goal-pursuit.

2.2.1 An overview of the studies

We test our main hypothesis in Experiment 1. The type of interaction (cooperative vs competitive chasing) presented during the familiarization phase allows us to make differential predictions about infants' expectations (and corresponding looking behavior) about the type of distribution of the benefits they anticipate the chasers to engage in during the test phase (sharing vs not sharing). If infants form a representation of the cooperative intentions to jointly achieve a shared goal in the Cooperative Chase condition, they should expect the participants to share the goal when obtained - an outcome coherent with cooperation - , so the violation of this expectation in the test phase (not sharing the result of the participants' coordinated goal-pursuit) should lead to an increase in looking times. In contrast, in the Competitive Chase condition the opposite pattern of results is predicted. If during familiarization infants' attributed catching the chasee as the individual goal of each chaser, respectively, that they pursue independently of each other, the sharing the outcome during the test phase should seem unexpected (and lead to longer looking times) while consuming the outcome alone by the agent first catching it would be seen as coherent with the achievement of an individual goal (and so should be less surprising).

Experiment 2 is a control condition, in which no cues of cooperation or competition are present. This allows us to ensure that the looking time patterns induced in Experiment 1 are not the result of some default expectation about sharing resources by agents in general but that they reflect the differential expectations induced by the kind of goal directed interactions observed between the protagonists. The subsequent experiments aimed to provide further supporting evidence in favor of our proposal. The goal of Experiment 3 was to replicate and generalize our initial findings (in Experiment 1) by employing a different set of cooperative and competitive cues. In Experiment 4 we removed the chasee from the familiarization events in order to test whether simply observing the different types of interactive patterns (indicating coordination vs hindering) without a goal being pursued is sufficient on its own to produce the same expectations about resource distribution. In Experiment 5 we further explore this idea and test whether information about a potential goal help infants to form expectations about sharing.

2.3 Experiment 1. Cooperative vs competitive chase and the distribution of the achieved benefits

2.3.1 Participants

Participants were fourty-eight full-term 13-month-old infants equally distributed between the Cooperative Chase Condition (11 females, mean age = 13 months 14 days, range 13 m 0 d to 13 m 26 d) and Competitive Chase Condition (10 females, mean age = 13 months 16 days, range 13 m 0 d to 14 m 0 d). Twelve additional participants tested but excluded from the final sample: nine due to fussiness, two for equipment failure and one for experimenter's error. Participants were recruited from the larger Budapest area. Parents signed an informed consent before taking part in the study, and all participants received a small toy as a gift for their participation. This research complied with relevant ethical regulations and was approved by the Hungarian Ethical Review Committee for Research in Psychology (EPKEB).

2.3.2 Procedure

Infants were tested in a quiet, dimly lit room. They sat on their caregivers' laps approximately 60 cm away from the computer monitor. The caregivers wore darkened glasses, so that they could not see the stimuli. They were instructed not to interact with the child in any verbal or non-verbal manner. Furthermore, if the infant turned completely away from the stimulus for more than 5s, the caregiver was instructed to turn him back in the initial position facing the screen. This procedure ensured that infants could freely turn away when they were not interested in the display but could be reoriented for a next trial without interfering with the measurements.

Infants saw 4 familiarization movies followed by 4 test trial movies. Familiarization movies presenting cooperative and competitive scenes were administered between subject. Each participant saw, 2 test movies depicting the sharing condition vs. 2 of the not sharing condition in ABAB order. Half of the infants saw the sharing outcome first, and half - not sharing outcome first. The last frame of each test movie remained still on the screen until the infant looked away for more than 2 consecutive seconds, or else looked at the screen for more than 30 cumulative seconds.

The experiment was ran on an Apple Mac Pro Quad Core 2.8 computer, controlled by PsyScope X (Cohen, MacWhinney, Flatt, & Provost, 1993). The stimuli appeared on a 24-inch TFT screen.

The experimenter monitored infants via the camera placed above the screen from a separate room. The recordings were further analysed offline.

2.3.2 Stimuli

Familiarization trials

Familiarization movies consisted of 3D animations depicting three spheric agents moving on a grey surface. Two bigger agents, the "chasers", were of the same size and blue colour (3°5’ in visual angle), and the chasee was a pink-coloured ball (2°3’), approximately 30% smaller. The scene also depicted two large rectangular stationary objects (7°4’ x 4°5’ and 13°2’ x 4°5’ for the two objects), together occupying about 10% of the screen, located close two each other and forming a long corridor between them.

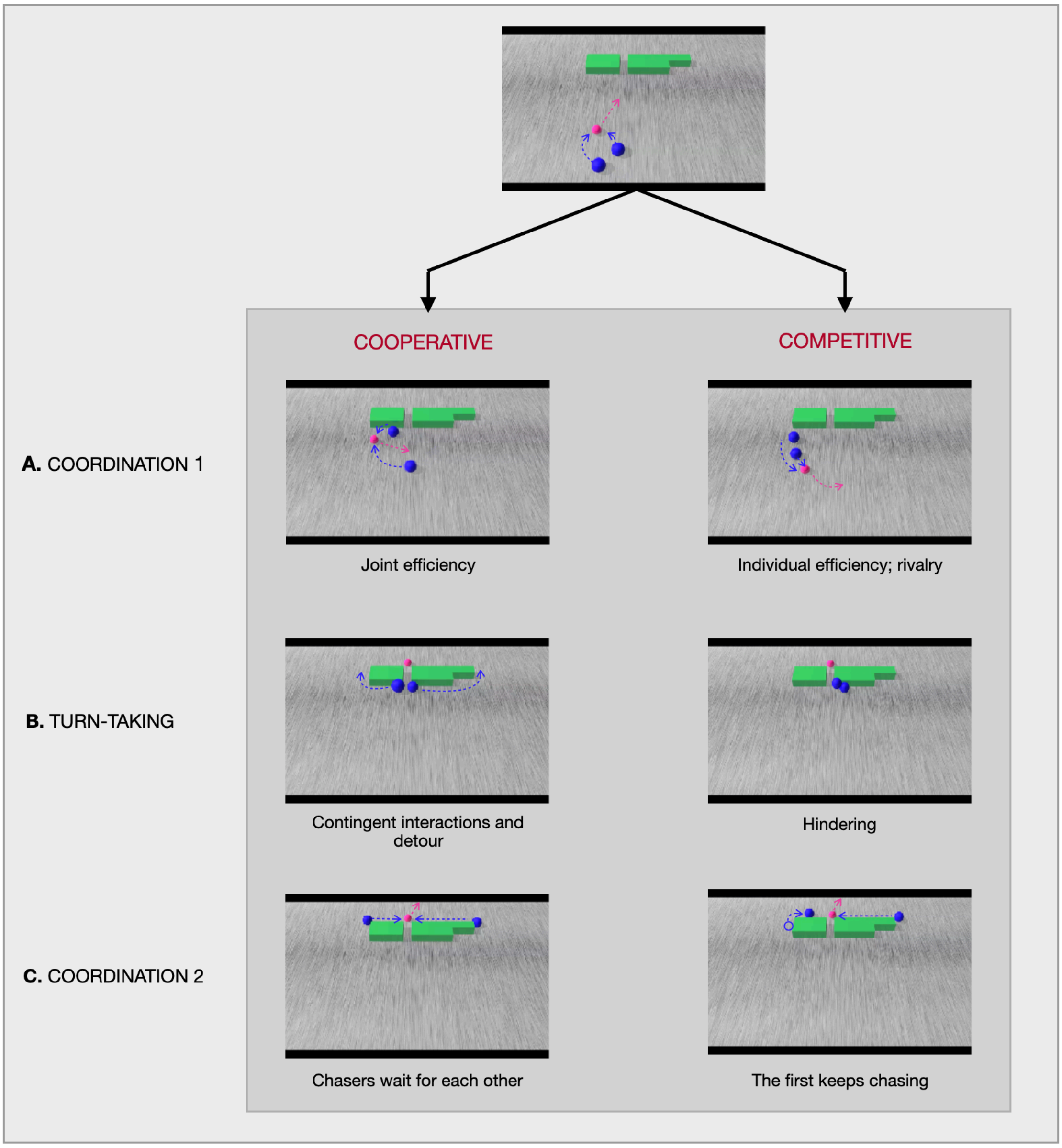

Figure 1. *Familiarization trials timeline in Experiment 1. The left panels illustrate the coordination cues presented to the group of infants in the Cooperative Condition. The right panels illustrate the scene presented to the group of infants in the Competitive Condition: the coordination was absent with the chasers hindering each other during the chase.*

The diameter of the corridor was fixed such a way that it allowed only for the chase to cross. Thus, these structures formed an "obstacle" determining the possible motion trajectories the protagonists could perform. The two kind of interactions that the agents performed in the

Cooperative Chase and the Competitive Chase Condition unfolded according to a well-defined protocol.

Cooperative Chase Condition

Each familiarization trial presented for the participants in the Cooperative Chase Condition (figure 1) started with the agents entering the scene, first the smaller chasee, immediately followed by the two chasers. The interaction between the agents followed a script that was well defined: coordinated chasing pattern, intermingled with turn-taking signals and adjustment to each other’s actions (e.g. waiting).

The interpretation of the event as chasing was ensured by incorporating two of the strongest cues identified by previous research to induce in infants the impression of a goal-directed chasing action (Frankenhuis et al, 2013): acceleration and attraction ("heat-seeking"). Chasers pursued the chasee in a "heat-seeking" manner with sudden directional changes and speed acceleration towards the chasee. Furthermore, chasers’ motion was in accordance with joint efficiency rather than individual efficiency (fig. 1A): each chaser acted taking into account the movements of the partner (for example, helping to decrease the distance between the chasee and the partner, even if it increased its own distance from the chasee).

After the initial phase of chasing (~ 8 s) the agents arrived at the objects forming an "obstacle" for the chasers. The smaller-sized chasee, however, continued to move uninterruptedly passing through the small gap (2°32’ forming a thin “corridor”, almost the same size as the evader) between the obstacles and stopped on the other side of the obstacles. Both chasers tried to follow it through the gap but – being too large to fit in – they could not get through but bumped back from the obstacle instead.

After each chaser performed several failed attempts, they stopped and engaged instead in distal interactions with each other in a turn-taking manner. In particular, they performed a contingent turn-taking exchange of behavioral displays such as expanding and shrinking in turn while emitting squeaking sounds of different pitches (Figure 1B). Apart from presenting evidence of a high degree of coordination of distal actions of interacting agents, turn-taking contingent reactivity of this kind has been shown to be a cue of ostensive communication and communicative information exchange for preverbal infants (Tauzin and Gergely, 2019).

Following the turn-taking behavioral exchange, the two chasers started to move in the opposite directions apparently to make a coordinated detour around the obstacle from it's two sides (Figure 1.C). Crucially, due to the uneven and asymmetric shape of the two sides of the obstacle, one of the chasers arrived to the other side earlier than the other chaser. Even though the first chaser, having arrived earlier, could have immediately (and individually) start to pursue the chasee on the other side, he did not, but "waited" instead until it's partner, the other chaser has arrived at the intended position at the other side of the obstacle. Once both arrived, they simultaneously started to move towards the chasee. The scene ended with all three agents moving outside the screen, continuing the chase.

The total length of a familiarization movie was 20 seconds.

Competitive Chase Condition

Familiarization movies were similar to those of the previous condition, depicting three agents involved in a chasing event around an obstacle. However, the behavioural cues of the chasers indicated a competitive rather than a cooperative pattern of interaction between them, demonstrating two individual competing for a single goal instead of cooperating for one common goal.

The basic event structure is similar to the one presented in the Cooperative Chase Condition. The movements and low-level features of the stimuli (e.g. speed of the movements, acceleration, number of turns of the agents) were loosely matched to those of Cooperative Chase Condition. However, the indicative cues of cooperation (joint efficiency, communicative turn-taking, "waiting" for the partner) were absent, and replaced with matching competitive cues: i.) Instead of jointly efficient chasing of the prey with the partner that was used in the Cooperative Chase Condition, here agents demonstrated individual efficiency only (taking the shortest path to the chasee) (Fig. 1A) intermingled with attempts to prevent the competitor from catching the prey (e.g. chaser A bumped into chaser B forcefully, pushing it away from the chase or chaser B moved between chaser A and the prey, blocking chaser A from catching the prey); ii.) instead of contingent turn-taking reactivity agents pushed each other away from the chase (Fig. 1B); iii.) upon arriving to the corner of the obstacle first, the chaser did not wait until the second agent arrive but rather continued the chasing immediately, indicating that they prioritize individual efficiency (Fig. 1C). All familiarization movies in both conditions followed the above structure with slight variations (e.g. in the acceleration and turns of the agents).

Test trials

The central event of all test movies was catching and consuming the prey by the chasers.

The scene depicted a large centrally located area surrounded by solid barriers, taking up around 60% of the total scene length and 30% of the scene hight. This barrier had two openings ("entrances") on either side. Soon after the agents entered the scene the chasee accessed the enclosure through the “entrance” on the right side (~ 4 s) (fig. 2A), followed by one of the chasers, while the second chaser made a detour to the second “entrance” on the other side (fig. 2B). The first chaser reached and contacted the prey at the centre of the enclosure /"fencing" (catching event) and both stopped. The following event varied in accordance with the test conditions. In the "sharing" condition the first chasee did nothing with the prey caught, they stayed still until the second chaser also arrived at the prey. At this point, the two chasers start eating the chase: taking turns bite after bite (fig. 2C). In the "not sharing" condition, the first chaser started to eat the chase immediately after catching it and consumed it on its own, finishing the last bite by the time the second chaser arrived. In each test condition the prey was consumed in the same amount of bites. The total length of test movies was 12 seconds.

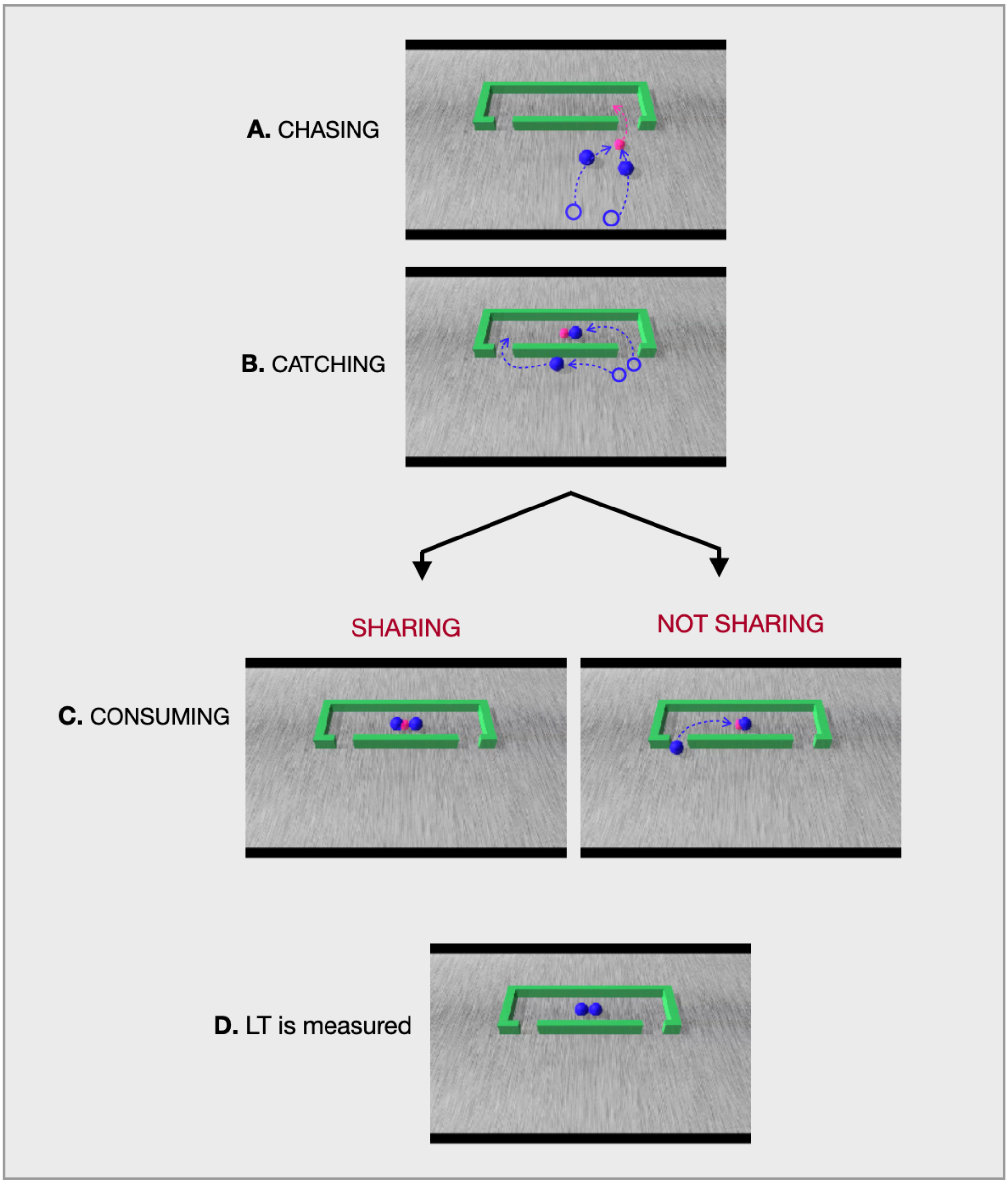

Figure 2. The structure of the test trials timeline in Experiment 1. All test trials started with a chasing event, where the chasers where the chasers initially follow the target together (A) then their trajectory separates (B). Each participant in both Cooperative and Competitive groups saw two outcomes (C): in Sharing outcome agents consumed the prey together and in Not Sharing outcome one of the agents consumed it alone. Each scenario results in scene with the two chasers (D). In each trial this scene remains on the screen till timeout criteria is satisfied.

2.3.4 Results

Looking time was calculated based on off-line coding of the video recordings. Half of the sample in each experimental group (24 infants in total) was randomly selected and coded by a second coder. The inter-coder agreement was high, with correlational coefficient of 97.8% for participants in the Cooperative Chase Condition and 98.4% for participants in the Competitive chase condition.

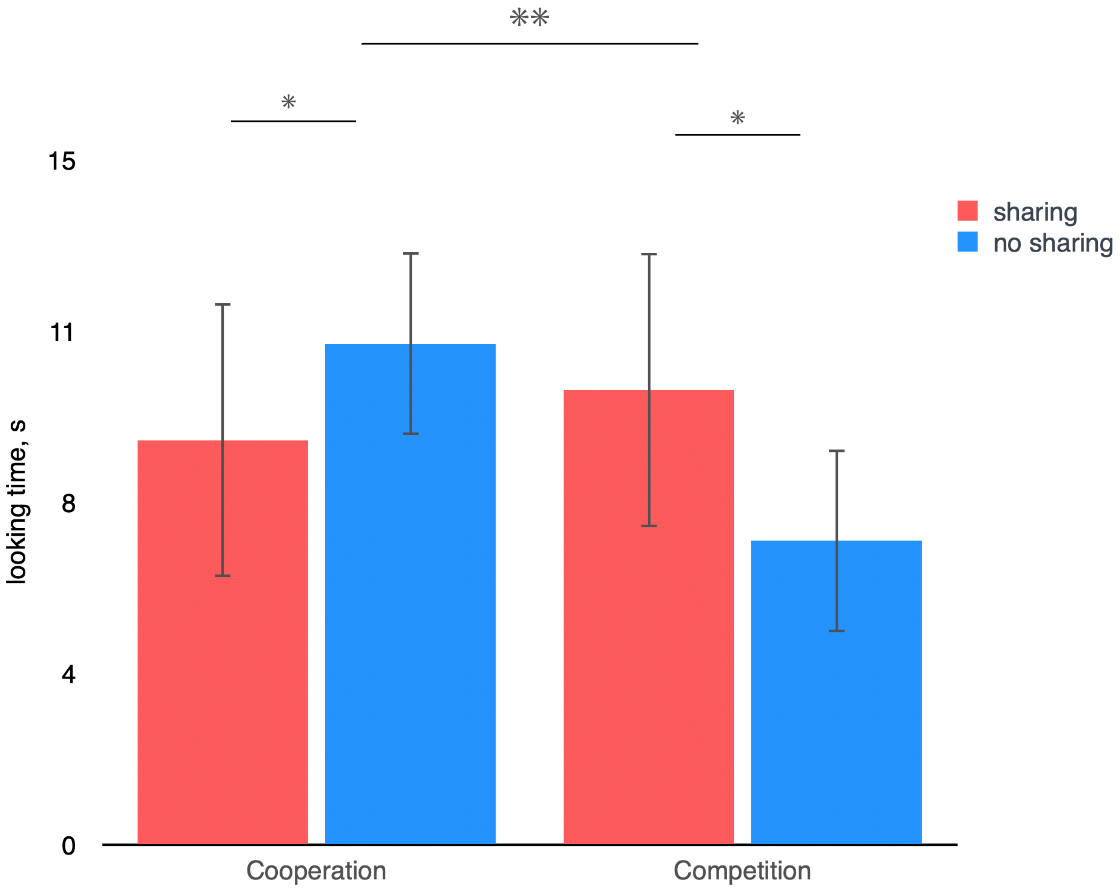

Figure 2. *Mean looking time in case of sharing and not sharing outcomes in cooperative and competitive conditions in Experiment 1. Infants are surprised if agents do not share after seeing the cooperative chase (longer LT in not sharing outcome). In the competitive condition, on the opposite, infants are surprised by the sharing outcome. Error bars represent standard deviations.*

A 2x2 ANOVA with condition (cooperative vs competitive) as between-subjects factor, outcome (sharing vs not sharing) as within- subjects factor, and participants as a random factor yielded a significant interaction between condition and outcome (F (1, 46)=6.135, p=.017), suggesting that the infants' expectations of the equal or unequal distribution of the benefits are modulated by the observed agents' cooperative and competitive behavioural patterns manifested during the chase familiarization.

We predicted that if infants interpret the cooperative cues observed in the chasing event of Experiment 1 Cooperative Chase Condition as indicating a common goal being jointly pursued by collaborative partners, they will expect the collaborating agents to distribute the gained goods equally (sharing). This is confirmed by the planned analysis of looking time collected in the Cooperative chase condition: infants reacted with longer looking time at the scenes presenting no sharing ($M_{NotSharing}$=10,92 s, SD=6.08) in contrast to those scenes that resulted in sharing ($M_{Sharing}$=8,85 s, SD=6.16, F(1, 23)=4.85, p=.037; $\eta^2 p$=.17). At the individual level, 16 out of 24 babies showed looking pattern in the predicted direction (p=.07 , binomial test)[3].

In contrast, when the chasing agents demonstrated cues of competitive behavior that suggested that catching the prey is their individual goal, infants did not expect the agents to share the "prey". This is indicated by their significantly longer looking times when observing the sharing outcome ($M_{Sharing}$=9.95 s, SD=5.5 s) than when the prey was not shared ($M_{NotSharing}$=6.6 s, SD=4.07 s; F(1, 23)=5.6, p=.025; $\eta^2 p$=.19)). This result was also confirmed at the individual level, with 18 out of 24 babies showed looking time in the predicted direction (p=.01 , binomial test).

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[3] This finding was directly replicated, see Appendix A, section 6.2

We have performed an additional analysis in order to check whether the order of test presentation (seeing sharing outcome first versus seeing not sharing outcome first) affected participants' looking behaviour. For each condition we performed a 2x2 ANOVA with order of presentation ("sharing first" vs "not sharing first") as between-subjects factor, outcome (sharing vs not sharing) as within- subjects factor, and participants as a random factor,. We found no interaction between order of presentation and outcome in the Cooperative Chase condition (F (1, 22)=0.128, p=0.72),. The analysis yielded a significant interaction in the Competitive Chase condition (F (1, 22)=24.452, p<0.001), suggesting that infants looking times were modulated by which outcome they saw first. Post-hoc Scheffe tests revealed that the effect was mainly coming from infants who saw "sharing" outcome first (infants looking longer at sharing p<0.0001), while the looking time difference at the outcomes was only at a tendency level (p=0.09) in those participants who saw "not sharing" first.

These results show that infants expectations of resource sharing was modulated by the type of interaction between the agents: infants expected agents who cooperated in achieving their goal to share the resource, while holding an opposite expectation for competing agents - infants were surprised if they shared. Even though our hypothesis was generally confirmed, a few questions remain to be answered: the role of the order effect in the Competitive Chase condition has to be addressed. It is also unclear where the effect is coming from: there is a possibility that one of the expectations for resource distribution is a default expectation, and only one of the manipulations actually produces an effect. It is also unclear what is the role of particular cues, and how robust is the effect in case the cues for cooperation and competition are changed. We address these questions in the following experiments.

2.4 Experiment 2. Default expectations for resource distribution

Distributing resources among individuals may be a general expectation largely shared by all members of a group. It is possible therefore that human infants may have some default expectations, such as a bias for expecting sharing resources among individuals by default, independently of the particular history of interactions that these individuals. Thus, Experiment 2 was designed to explore the potential role that such default expectations may have played in directing infants' expectations about distribution of resources in the different conditions of Experiment 1. In order to test the possibility that infants have a default preference for either of the events (sharing or not sharing between agents), we presented infants with the test stimuli of Experiment 1, which however was not preceded during familiarization by any interaction (neither cooperative nor competitive) between the two agents. To eliminate any possibility for the familiarization events being interpreted as either a cooperative or competitive chasing event, we removed the chasee, and created a set of independent motion patterns following simple geometrical trajectories (e.g. line or circle) for the two other agents eliminating any sign of interaction.

2.4.1 Participants

Participants were twenty-four full-term 13-month-old infants (12 females, mean age = 13 months 12 days, range 13 m 01 d to 13 m 26 d). Three additional infants were excluded from the final sample: two due to fussiness and one for equipment failure.

Procedure and apparatus

The procedure and apparatus were identical to those developed for Experiment 1.

2.4.2 Stimuli

Familiarization trials

Two blue spheric objects (identical to the "chasers" in two conditions of Experiment 1) entered the scene one by one from different sides. There was a 5 s difference between their appearance. Each ball moved toward a predetermined area of the screen, performed a highly predictable path, never intersecting the trajectory of the other ball. One ball was following either a circular in half of the trials or a rectangular-shaped path; while the second object moved either in a straight line in half of the familiarization trials, or in a triangular trajectory. Both performed their respective movements for ~15 seconds.

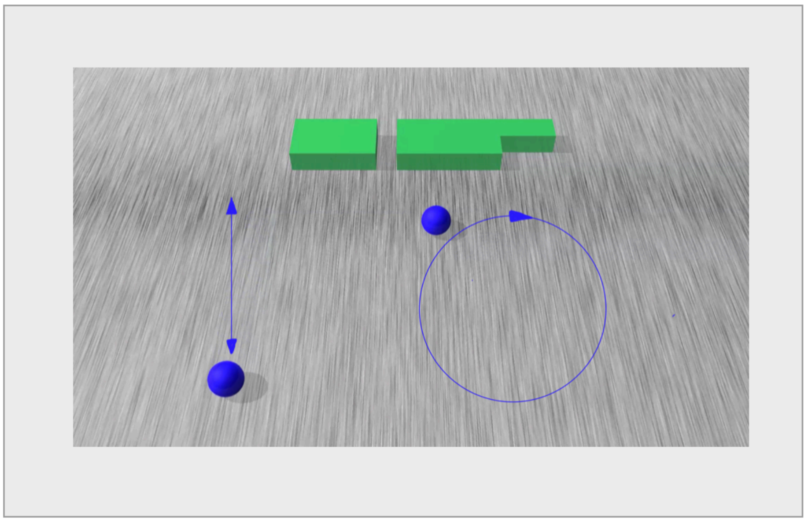

Figure 3. Agents' movements in Experiment 2.

Some of movement cues, like accelerating and decelerating spontaneously was the same as those introduced in the previous experiment, but these entities never interacted with one another, and left the scene independently with 2 s difference. The total length of a trial was 20 s.

Test trials

The test trials were identical to those of Experiment 1.

2.4.4 Results

Looking time was measured by off-line coding of the video recordings. Half of the sample (12 infants) was randomly selected and coded by a second coder as well. The inter-coder agreement was high, with a correlational coefficient of 96.1%.

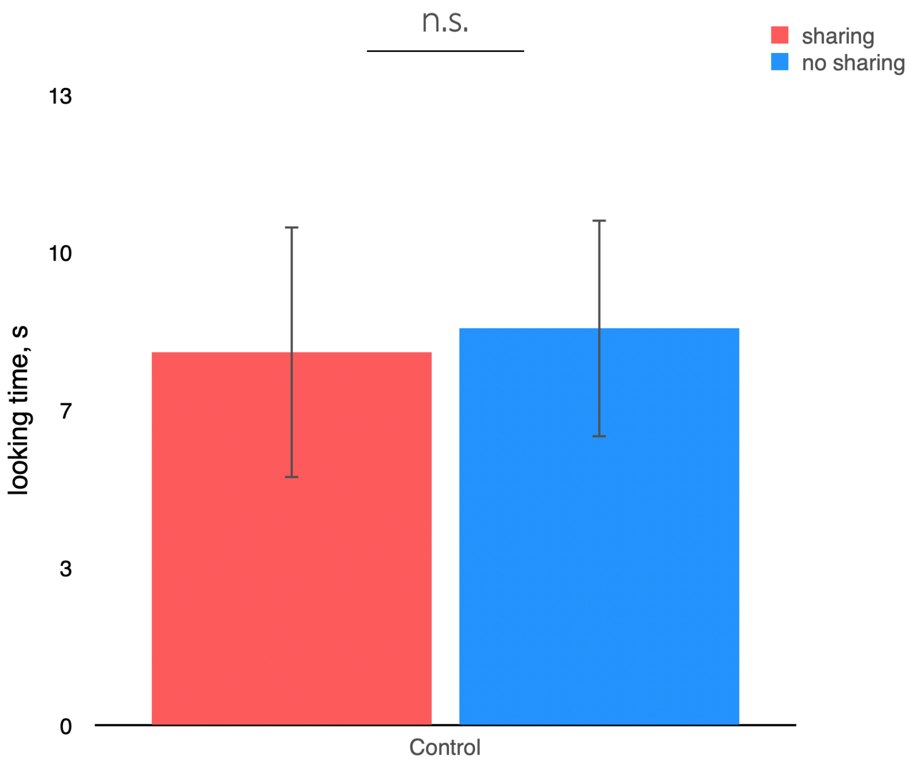

Figure 4. Mean looking time in test conditions of Experiment 2. Error bars represent standard deviation.

A two way ANOVA with condition (sharing vs not sharing) as within-subjects factor, showed no significant difference ($M_{Sharing}$ = 7,69 s, SD=5.2 s; $M_{NotSharing}$ = 8,18 s, SD=4.5 s;

F(1,23)=0.41, p=.53; η2p=.017) between the looking times collected in the two experimental conditions.

The results demonstrate that unlike in Experiment 1 infants had no expectation for either sharing or not sharing the reward by the agents during the test trials in the absence of previous experience with cooperative or competitive interactions (or, for that matter, any interaction) between them. This results also suggests that infants' expectations about the sharing behavior of the agents in the test phase were indeed modulated by the type of the interaction they saw during the familiarization.

2.5 Experiment 3. Exploring the role of various cues indicating cooperation or competition

The results of Experiment 1 and Experiment 2 left a few questions unanswered. Experiment 1 incorporated multiple cues to induce the type of interaction between the agents we aimed to investigate: on the one hand, joint efficiency, turn-taking contingent reactivity, and waiting for each other were used as cues to indicate a cooperative attitude and interactive pattern; while on the other hand, hindering the rival, only individual efficiency and absence of waiting were used as cues to indicate a competitive attitude and interactive pattern. Even though infants clearly distinguished between these behavioural patterns, we cannot be sure which of these cues were necessary and to what degree they contributed to inducing the categorization of the interaction.

In order to make sure that the effect was not cue-specific, and control for small perceptual differences, the effect has to be replicated with different behavioural cues. If the theoretical model we rely on is correct, and there is a cognitive adaptation that allows humans to make inferences about the distribution of the resources in function of the invested work, then this mechanism should be flexible enough to recognize cooperative (or competitive) investment instantiated in various different ways. If that assumption is correct, a study using perceptually different cues of cooperation and competition should yield the same results. We test this possibility in the experiments presented below, where we narrowed down the cues of cooperation to only one: joint instrumental action.

2.5.1 Participants

Participants were forty-eight full-term 13-month-old infants equally distributed between the Joint Action Condition (12 females, mean age = 13 months 12 days, range 13 m 03 d to 13 m 25 d) and Individual Action Condition (10 females, mean age = 13 months 14 days, range 13 m 03 d to 13 m 28 d). Participants were from Hungarian- speaking families from larger Budapest area, with no visual or hearing problems. Seventeen infants were excluded from the final sample: nine due to fussiness, five for equipment failure, two for reaching the maximum looking time in two trials or more, and one for experimenter's error. Similarly to the previous experiments participants' legal representative signed a consent form.

Procedure

The procedure and apparatus were identical to those developed for Experiment 1.

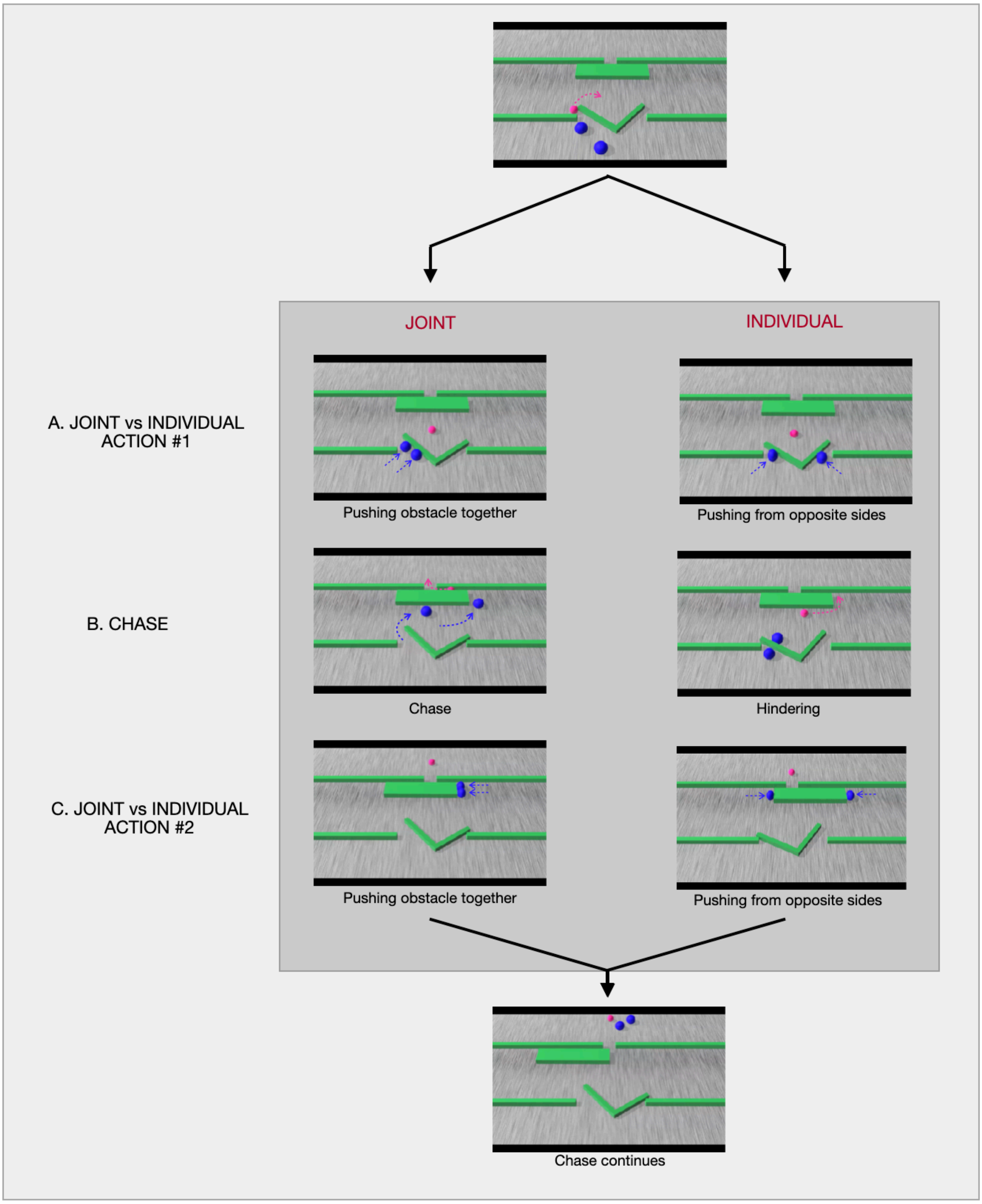

Figure 5. Familiarization trials timeline in Experiment 3. One group of infants saw the Joint Action condition with two agents following the chasee in cooperative fashion and performing joint actions. Another group of infants saw the Individual Action condition with chaser agents hindering each other and performing individual actions.

2.5.2. Stimuli

Familiarization trials

Similarly to Experiments 1 and 2 familiarization movies consisted of 3D animations depicting three spheric agents moving on a grey surface - two "chasers" and one smaller "chasee". We changed, however, the characteristics of, the "obstacles". Now the scene depicted two types of obstacles. There are two parallel walls positioned horizontally with one central opening. Each opening was obstructed by different obstacles such that the chasers cannot pass the remaining corridors unless the obstacles are removed. The obstacle in front of the first entry point was a V-shaped structure. The object at the second entry point was a large rectangular structure (fig.5). In order to pursue the evader successfully, chasers had to move the obstacles from their way .

Joint Action Condition

Each familiarization trial started with the agents entering the scene, first the chasee, immediately followed by the two chasers. The chasee agent passed through the opening between the V-shaped obstacle and the wall due to its smaller size and stopped on the other side of the obstacle.

The first chaser, in an attempt to follow it bumped into the obstacle, being too large to fit into the opening. After that, it attempted to turn the obstacle away by bumping into it with force. Once it failed, the second agent repeated the movements, also failing to move the obstacle. After both of them failed, they performed the movement together, synchronously hitting one side of the obstacle and moving it slightly (fig. 5A). The agents repeated the movement, turning the obstacle away sufficiently to make the opening large enough for them to pass through it (fig. 5B). This scene lasted for 6 seconds.

Once the chasers passed the first obstacle, the chasee started to move fast to the second obstacle - a large rectangular shaped object covering the opening in the second "wall" - and going around the obstacle through the opening. It stopped on the other side of the obstacle (~3 s).

The chasers tried to follow it, and, similarly to the first obstacle, failed due the large size. Similarly, both agents tried to move the obstacle away separately, but failed. Following these attempts, they applied the force simultaneously, moving away the obstacle in two movements (fig. 5C, ~6 s).

The chasee started to move once the obstacle was removed and chasers could bypass the wall. Last three seconds of the familiarization trials depicted a chase, using the same perceptual cues evoking the chase interpretation as in the previous experiments: acceleration and attraction (Frankenhuis et al, 2012): chasers pursued the chasee in a "heat-seeking" manner with sudden directional changes with speed acceleration towards the chasee.

The scene ended with all three agents moving outside the screen, continuing the chase. Each familiarization movie lasted for 20 seconds.

Individual Action Condition

Familiarization movies were similar to those of the Joint Action condition, depicting three agents involved in a chasing event. However, the behavioural cues of the chasers indicated individual rather than a joint actions pattern, demonstrating two agents performing individual actions and hindering the rival instead of performing cooperative joint action for the common goal.

The basic event structure is similar to that of the Joint Action condition: the trials started with a short chasing event then the encounter with the obstacle with an opening that was sufficiently large for the chasee to pass passed through but not the chasers. They had find a way to displace the obstacle.

The movements and low-level features of the stimuli (e.g. speed of the movements, acceleration, number of turns of the agents) were loosely matched to those of Joint Action condition. However, the indicative cues of cooperation - joint instrumental actions were absent and replaced with matching individual competitive actions.

In particular, after the first unsuccessful attempt of the first chaser to move the obstacle, the second one instead of performing the same action simultaneously (and doubling the force exerted over the object), went to the opposite side and attempted to move it from the other direction. Initially, the obstacle moved slightly but not sufficiently for the agent to pass. Finally, the second chaser moved the obstacle sufficiently to pass through the opening. It caused the other chaser to abandon his initial attempts, go around the obstacle and trying to pass through the same opening (fig. 5A). In this moment, however, the second chaser pushed the obstacle back to the initial position from the other side, therefore, hindering the competitor and making it take a detour around the obstacle once again (fig. 5B). The scene lasted for 6 s.

Once the chasers passed the first obstalce, the chasee moved fast to the second obstacle - a large rectangular shaped object covering the opening in the second "wall" - and going around the obstacle through the opening. It stopped on the other side of the obstacle (~ 3 s).

Similarly, to the first obstacle, the chasers failed to cross the opening due to the large size. Again, both agents tried to move the obstacle away separately from different sides but failed. After two attempt of each, the first chaser was able to move away the obstacle in two movements (another ~ 6 s, fig. 5C). The chasee started to move once the obstacle was removed and chasers could bypass the wall. Last three seconds of the familiarization trials depicted a chase.

In both conditions, all familiarization movies followed this structure with slight variations (making 4 movies per condition): the actions were performed both on the left and the right side of both obstacles. Total length of familiarization movies was 20 seconds.

Test trials

The test phase was identical to the one used in the previous experiments.

2.5.3 Results

Preparation of the data for analysis was performed as in the previous experiments. Half of the sample in each study (24 infants) was randomly selected and coded by the second coder. The inter-coder agreement was high, with correlational coefficient of 97.8% in Joint Action condition and 98.4% in Individual Action condition.

In order to find out whether infants' looking time after the (equal or unequal) distribution of the benefits achieved was modulated by the different (cooperative or competitive) behavioural patterns of the chase events we ran a 2x2 ANOVA with condition (cooperative vs competitive) as between-subjects factor, outcome (sharing vs not sharing) as within- subjects factor. This ANOVA yielded a significant interaction between condition and outcome (F (1, 46)=7.525, p=.008; $\eta^2 p$=0.14), suggesting that the infants' expectations of the equal or unequal distribution of the benefits are modulated by the agents' cooperative versus competitive attitude and behavioural patterns during the chase event.

Similarly to Cooperative Chase Condition of Experiment 1, we predicted that if infants interpret the cues implemented in the Joint Action condition as signaling cooperation they will expect the collaborating agents to distribute the gained goods equally. This hypothesis was confirmed by infants longer looking times in the non-sharing than in the sharing condition ($M_{NotSharing}$=10.2 s, SD=5.25 vs. $M_{Sharing}$=6.16 s, SD=3.1, F(1, 23)=14.12, p=.001; $\eta^2 p$=0.37). At the individual level, the results were converging with 18 out of 24 infants looking in the predicted direction (p=.01 , binomial test).

In contrast, and similar to Experiment 1 Competitive Chase Condition, when the chasing agents demonstrated cues of individual competitive actions, infants did not expect the agents to share the "prey". This is indicated by their significantly longer looking times when observing the sharing outcome (($M_{Sharing}$=11.19, SD=6.2) than when the prey was not shared ($M_{NotSharing}$=7.34, SD=4.7) (F(1, 23)=9.4, p=.005, $\eta^2 p$=0.29)). This looking time pattern was present in 19 out of 24 participants (p=.003 , binomial test).

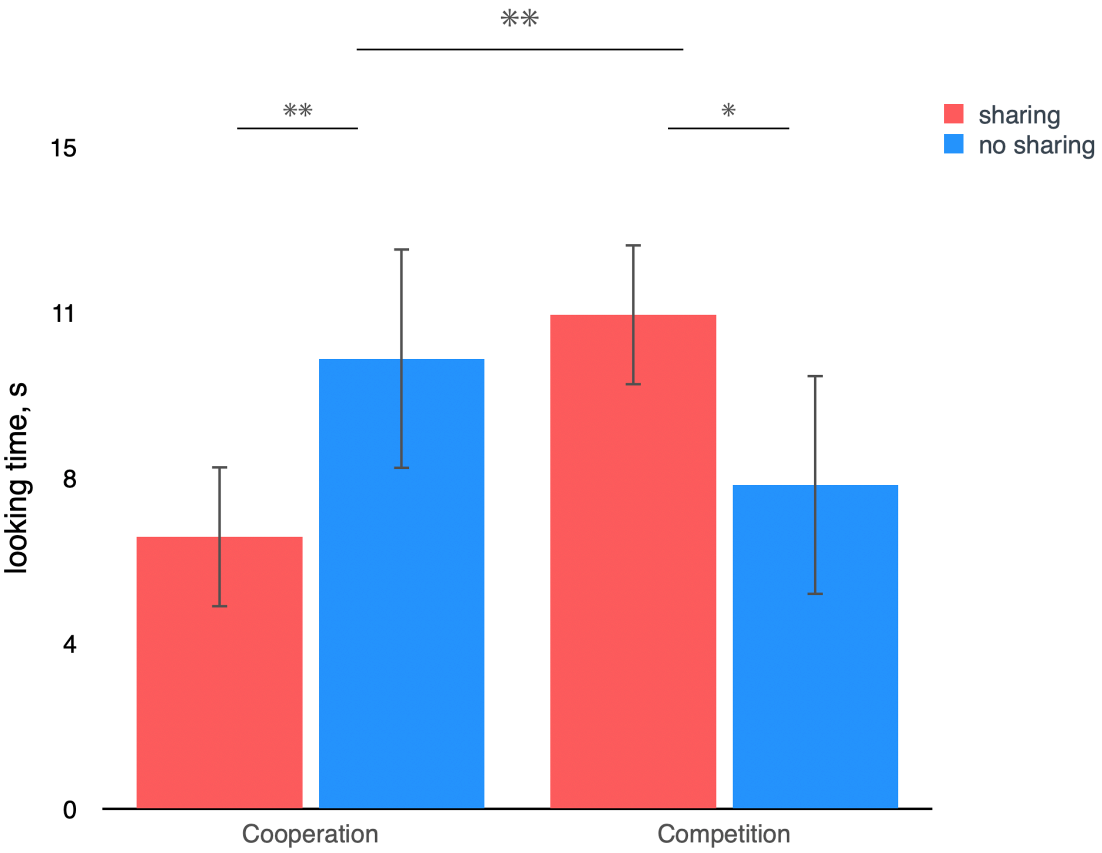

Figure 6. Mean looking time in case of sharing and not sharing outcomes in cooperative and competitive conditions in Experiment 3. Infants are surprised if agents do not share after seeing the cooperative chase and joint actions (longer LT in not sharing outcome). In the competitive condition, on the opposite, infants are surprised by the sharing outcome. Error bars represent standard deviations.

We have performed an additional analysis in order to check whether the order of test presentation (sharing outcome first vs. not sharing first) affected participants' looking behaviour. A 2x2 ANOVA with order of presentation as between-subjects factor and outcome (sharing vs not sharing) as within- subjects factor did not yield a significant interaction between order of presentation and outcome in Joint Action condition (F (1, 22)=2.9, p=0.098), as well as in Individual Action condition (F (1, 22)=0.87, p=0.36).

Given the similarity of the looking time patterns in Experiment 1 and Experiment 3 these results confirm and strengthen the findings of the previous studies. Furthermore, by confirming that infants are able to make inferences about how resources should be distributed as a function of work invested using two different sets of cues we demonstrate that they can make such inferences flexibly depending on the context. This flexibility suggests that the cognitive apparatus responsible for these expectations can perform such inferences in a variety of contexts and based on different cues. In the next study we ask whether only cues of coordination or rivalry between the agents are enough to produce the same effect.

2.6 Experiment 4. Can cues of mutual coordination alone induce expectations of sharing?

The previous results suggest that infants expect cooperative partners to share the benefits, and the expectation for competing agents is the opposite. However, there are a number of questions raised by these findings concerning the generalizability of the expectations about resource distributions, and the possible limiting conditions that constrain their induction. For example, are the expectations constrained to inferences about distributing only the particular goal outcome achieved? Do they apply selectively or restrictively to domain-specific kinds of goals only (as in our case, the domain of chasing a “prey” to consume)? And, importantly, on what kind of informational basis do differential expectations about resource distribution rely on?

In particular, recognizing the type of interaction (e.g., mutual coordination of behaviours among agents) might be sufficient to induce a general expectation of sharing resources among the coordinating partners. This could be plausible from the point of view of recent theoretical proposals (see Spelke, 2016) that postulate a separate core domain of 'social beings', which is initially not integrated with the domain of goal-directed agents. 'Social beings' form affiliative groups whose members share core properties such as having similar features (like the two blue round agents ("chasers") in our studies) and acting similarly by mutually aligning their behaviours with each other (e.g., Powell and Spelke, 2013). Alternatively, such interactions involving mutual coordination need to involve a shared goal that justifies the action coordination of cooperative partners in order to induce expectations of resource sharing among them.

To test these hypotheses - i.e., whether joint coordination in social interactions is a sufficient cue to induce an expectation of resource sharing or it is also necessary to attribute a shared goal and representing a corresponding goal object that is identical with the one involved in resource distribution - we ran two further experiments: Experiments 4 and 5. Experiment 4 was like Experiment 3 except that the chasee (the goal) was not present during the familiarization events. Thus, while the cue of goal-directed chasing was removed, the cues of mutually coordinated interactions between the two agents remained present during the familiarization phase of the Coordinated Actions condition: Infants saw two agents as they were coordinating their actions while pushing and moving obstacles together. In contrast, in the Individual Actions condition infants were familiarized to the two agents acting competitively pushing the obstacles on their own while also hindering the actions of their rival agent. In both conditions the actions observed remained goal directed, but they were not performed in the context of the goal of chasing a prey: rather the two agents aimed to push the obstacles out of their way to unlock the exits leading to the other side.

For both conditions the goal of catching the chasee (the ‘prey’) appeared only during the test phase, that unfolded exactly like in the previous experiments: the goal was either shared by the two agents or consumed alone by one of them. Due to the absence of the chasee during familiarization infants observed two agents perform coordinated joint actions (Coordinated Actions condition) or parallel individual actions (Individual Actions condition) that could in neither case be locally interpreted as being driven by the goal of catching the ‘prey’ (which only appeared later, during the test phase). This way, if infants had differential expectations about resource distribution during the test trials (sharing or not sharing the ‘prey’ by the agents), these could only be based on the different kinds of interactive behavioral patterns (coordinative versus competitive) that the two agents engaged in during familiarization (which did not take place in the context of goal-directed chasing).

Experiment 4, therefore, tested two alternative predictions. If the type of interaction between the agents (involving mutual coordination versus individual competitive actions) provides a sufficient cue to induce differential expectations about resource distribution, we would expect to replicate the same pattern of the results as found in the previous experiments. If, however, what matters is that the joint investment and mutual action coordination is performed in order to achieve the particular goal outcome that will be shared (or not) during the test phase, then infants will not generate differential expectations during familiarization about resource distribution between the agents concerning the reward that is presented only later during the test phase, so no differences in looking time between the conditions are expected.

2.6.1 Participants

Participants were forty-eight full-term 13-month-old infants equally distributed between the Coordination Condition (14 females, mean age = 13 months 14 days, range 13 m 04 d to 13 m 26 d) and Individual Condition (10 females, mean age = 13 months 11 days, range 13 m 04 d to 13 m 26 d). Eleven additional infants were excluded from the final sample: four due to fussiness, four for equipment failure and two for reaching the maximum looking time in two trials or more. Participants were from Hungarian- speaking families from larger Budapest area. Participants' legal representative signed a consent form.

2.6.2 Stimuli

Familiarization Trials

Familiarization movies were identical to those of Experiment 3 with the only exception that the chasee was removed. This way, the pattern of interaction between the agents - performing either joint or individual actions - and the instrumental goal of passing through the obstacle were preserved. As in Experiments 1 and 3 there were two groups of participants presented with either of the condition (Coordination or Individual).

Test trials

After the familiarization each participant saw 4 test movies. The test trial were identical to those used in Experiments 1-3.

2.6.3 Results

Looking time was calculated based on off-line coding. Half of the sample in each study (24 infants) was randomly selected and coded by the second coder. The inter-coder agreement was high, with correlational coefficient of 95.2% in Coordination Condition and 94.1% in Individual Condition.

We measured whether infants' looking time after the (equal or unequal) distribution of the benefits achieved was modulated by the different (cooperative or competitive) behavioural patterns of the events. In a 2x2 ANOVA with condition (Coordination vs Individual) as between-subjects factor, outcome (sharing vs not sharing) as within- subjects factor, showed interaction between condition and outcome (F (1, 46)=0.71, p=.4; η^2p=.015), suggesting that the infants' expectations of the equal or unequal distribution of the benefits were not modulated by the agents' behavioural patterns during the chase event.

We predicted that if infants interpret the cues of mutually coordinated joint actions observed during the familiarization events of the Coordinated Actions condition as indicative of the interactive agents' collaborative relationship, and mutual coordination would itself be a sufficient cue to attribute an attitude of resource sharing among the cooperating agents, infants would expect the agents to distribute equally the goods they gained in a different goal directed activity subsequently (i.e. during the chasing and catching the prey events of the test movies). However, if infants restrict their expectations about resource distribution to the specific context in which the cooperative interaction is carried out in order to obtain the particular shared goal outcome (chasing and catching the prey), then, in the absence of the goal of chasing the prey presented during the familiarization events, they will hold no particular expectation about resource distribution. The latter suggestion was confirmed. In the Coordinated Action Condition infants looking behavior did not differ significantly between the conditions ($M_{NotSharing}$=10.3 s, SD=5.64 vs. $M_{Sharing}$=7.6 s, SD=4.36, F(1, 23)=2.63, p=.11; η^2p=.1).

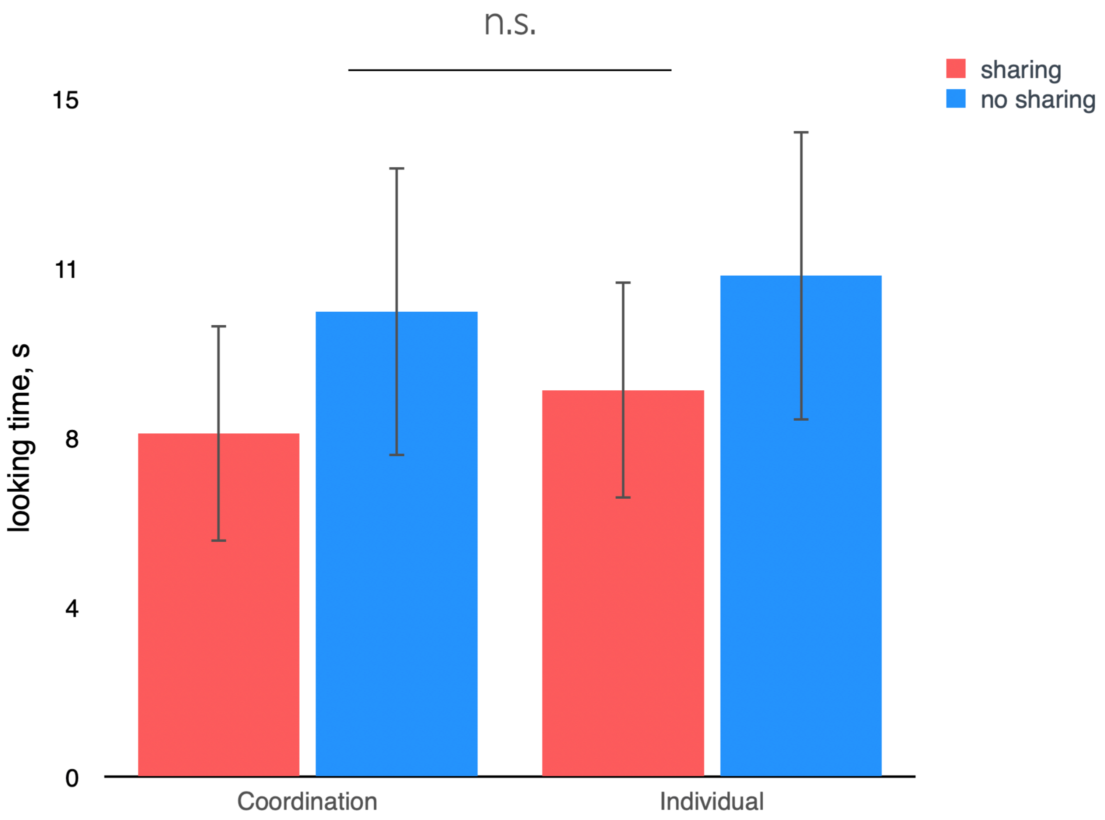

Figure 7. Mean looking time in case of sharing and not sharing outcomes in Coordination and Individual conditions in Study 4. Infants show no differential expectations about either of the conditions. The error bars represent standard deviations.

We have performed an additional explorative analysis to check whether the looking time pattern changed over the course of test trials: if this is the case, it would suggest that infants were aided by the exposure to the joint goal - catching the prey. In particular, we intended to see whether the looking time pattern in the first two trials was different from that of the last two trials. However, 2x2 ANOVA with block of trials (first two trials vs last two trials) as between-subjects factor, outcome (sharing vs not sharing) as within- subjects factor, showed no interaction between trial block and outcome ((F (1, 46)=3.32, p=.07; $\eta^2 p$=.06), suggesting that the infants' expectations did not change over the test phase.

Similarly, if infants recognized the pattern of interaction between the agents during the familiarlisation as competitive, but this type of interaction did not involve the goal of pursuing a prey to catch during the familiarization events, they would show no specific expectations as to lack or presence of resource sharing in relation to the prey caught during the test events. In the Individual Condition infants' looking times were not significantly different ($M_{NotSharing}$=11.09 s, SD=7.8 vs. $M_{Sharing}$=8.56 s, SD=5.23, F(1, 23)=2.08, p=.16; $\eta^2 p$=.08). Thus, targeted comparison of the main conditions performed by the two groups did not reveal any difference in looking time.

Overall, the interaction pattern between the agents performed in a context not involving the goal that will be shared later will not influence their expectations about how these specific resources will be distributed. Together this data suggests that infants did not form expectations about resource distribution based on the (cooperative vs competitive) behavioral patterns of interacting agents when they were observed in a context unrelated to the resource in question.

2.7 Experiment 5. Priming the goal of chasing facilitates attributing it as the shared goal

Even though the looking time differences found in Experiment 4 did not reach significantce levels, in the Coordinated Action condition we found a pattern of differential looking times as in the previous studies (infants looked numerically longer at the non-sharing test outcome). We hypothesize that when infants observed the mutually coordinated interactions of the jointly acting agents during familiarization, they were attempting to find and assign a shared goal that would justify the agents mutually coordinated joint actions. But the goal of jointly catching a prey was not immediately available to be attributed as the shared goal of the coordinated actions, as this goal was only presented significantly later (during the test phase) following the familiarization events.

In this experiment, we test whether by priming the goal concept of catching the prey already during the familiarization phase, we may be able to facilitate integrating the shared goal observed during the test trials later as being the shared goal that was driving the jointly coordinated interactions already during the familiarization events. To achieve such an effect in Experiment 5 we added two extra events to the familiarization phase that involved individual chasing of the prey. These events were presented additionally but independently of the mutual cooperative interaction events during the familiarization phase. By doing so we hoped to boost the goal assignment of chasing and catching the prey during the test events as having been the shared goal of the coordinated cooperative interactions observed during the preceding familiarization phase.

2.7.1 *Participants*

Participants were twenty-four full-term 13-month-old infants (13 females, mean age = 13 months 17 days, range 13 m 0 d to 14 m 0 d). Eleven additional infants were excluded from the final sample: four due to fussiness, four for equipment failure and two for reaching the maximum looking time in two trials or more.

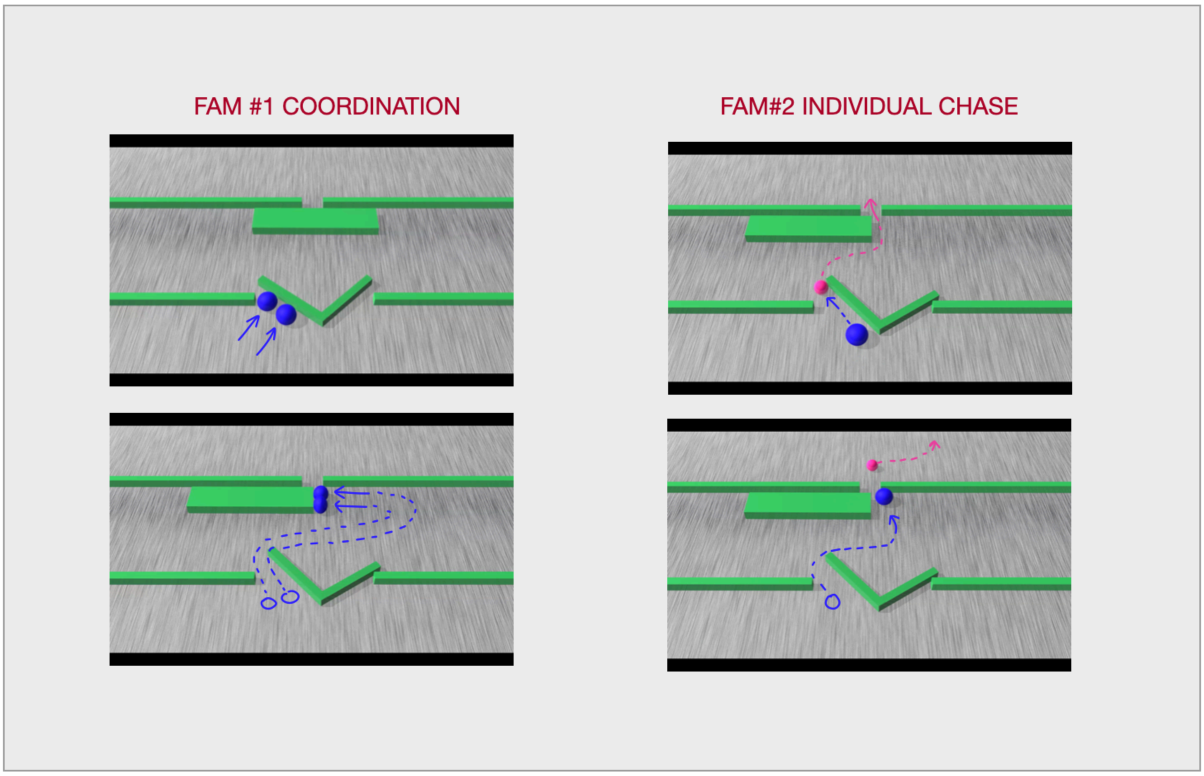

Figure 8. Familiarization trials in Experiment 5. Infants saw two types of movies during the familiarization: "coordination" trials with two agents coordinating over moving away the obstacles (but no chasee present), and "individual chase" trials with one chaser and one chasee present.

2.7.2 *Stimuli*

Familiarization Trials

There were 6 familiarization trials: 4 of them identical to the previous study (joint actions of two agents with no chasee present). Another two movies depicted an individual chase pattern: there was only one chaser and one chasee present. The setup of the obstacles was identical to other familiarization movies, with the exception that the blocks were already misplaced, so that the chaser did not have to move them away and went through the opening following the chasee.

Half of the participants saw the “individual chase” movie first, while the other half saw the “coordination” movie first. Thus, the order presentation was either ABBABB or BBABBA.

This way, all the elements of the original cooperative chase scenario (coordination between the chasers; and a goal-directed chasing action) were present during familiarization. If infants are able to integrate the goal of chasing by attributing chasing as the shared goal justifying the coordinated joint interaction of the agents, it might boost their understanding of the scenes and lead to form expectations about resource distribution.

Test trials

After the familiarization each participant saw 4 test movies. The test trials were identical to those used in the previous experiments.

2.7.3 Results

Looking time analysis (ANOVA with condition as within-subjects factor) showed that similar to the cooperative conditions of the previous experiments infants were surprised if the chaser agents did not share the prey, as indicated by longer looking times ($M_{NotSharing}$=8.38 s, SD=3.87 vs. $M_{Sharing}$=6.68 s, SD=3.82, F(1, 23)=5.08, p=.033; η^2p=.18). This pattern was evident at the individual level as well: 20 out of 24 participants looked in the predicted direction (p<.001 , binomial test). This suggests that infants were able to integrate the cooperative cue (coordination) of interaction type between the agents, and their potential goal (chasing) and successfully interpret the test phase of chasing and catching the prey as the common outcome of the cooperative venture.

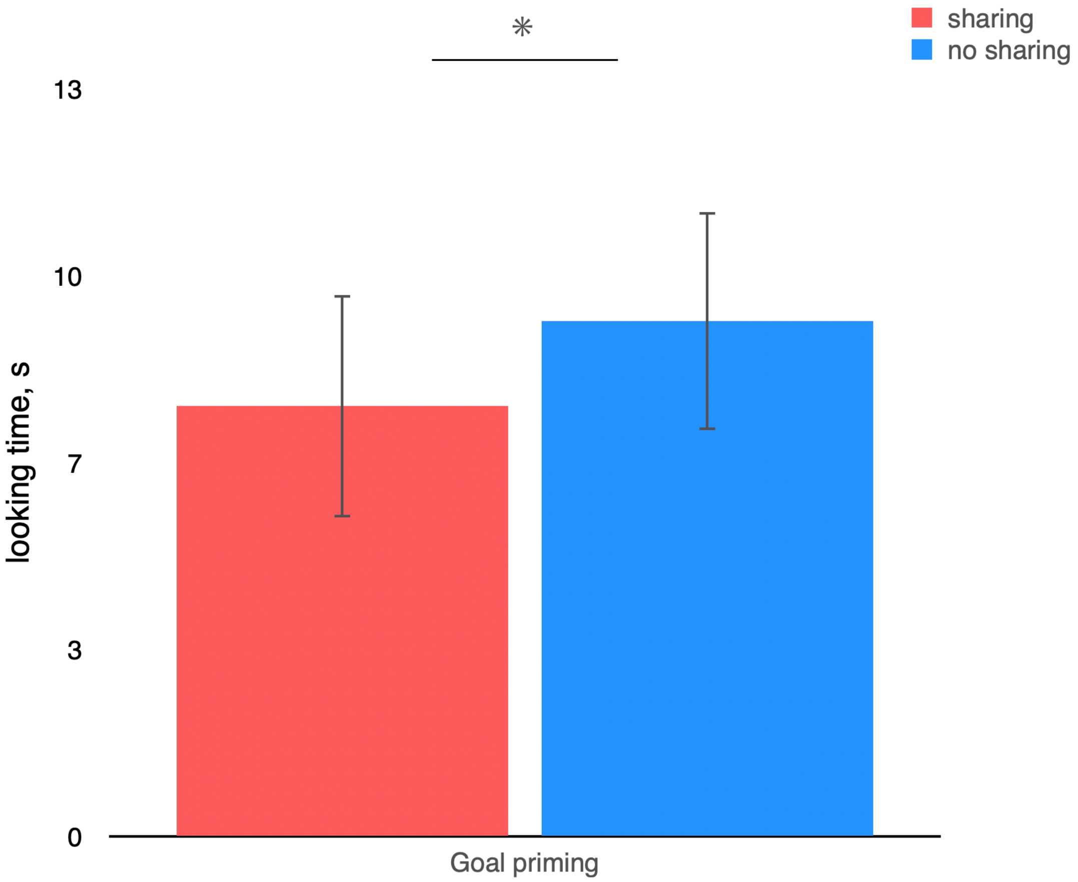

Figure 9. Mean looking time in case of sharing and not sharing outcomes in experiment 5. Infants are surprised if agents do not share the reward, as indicated by higher looking times in "no sharing" condition. Error bars represent standard deviations. Error bars represent standard deviations.

One way to reconstruct how the successful integration of the interactive events with the primed goal of the individual chasing event may have taken place is as follows. During familiarization in Experiment 5 we provided infants with two pieces of information in the

Coordinated Actions condition: that the two blue agents engage in mutual coordination and helping each other, and also that at least one of them (or both, but separately) have a goal of catching a prey. This then allows the individual chaser to follow the chasee through the now unblocked passage way given that the obstacles blocking it have been removed (this, however, is not the case for the first two “coordination” movies that half of the participants saw first). Hence the chasing and eventual catching of the prey could be facilitated by the cooperative effort of the two agent that removed the obstacle.

The cooperative interaction involving joint effort to remove the obstacle, therefore, could realize a sub-goal (opening the passage way) which facilitated (and contributed to the success) of the individual agent’s realization of his goal to catch the prey. This way the cooperative action could be interpreted as "preparing the grounds" enabling the chaser to catch the chasee, and so the cooperative joint efforts to achieve the sub-goal of removing the obstacle have also contributed to the goal of catching the prey, even if indirectly.

The objection to this interpretation, however, would be that the familiarization movies were intermixed, e.g. showing the individual chaser going through the opened obstacles before the cooperating agents removing them. We do not know how infants interpret these looped events, and the repeated videos does not seem to be a problem in all other experiments (e.g. chasers eat the prey several times). Possibly, this kind of discontinuity did not disrupt the interpretation of moving the obstacles as a subgoal for chasing.

In one attempt to clarify this matter, we checked whether the order of presentation mattered in producing the looking time pattern. Is it possible that infants who saw the “coordination” type of familiarization first, and “individual chase” only after (being more compatible with the interpretation we are exploring) differed in their looking pattern from the infants who saw the reversed order?

We have performed an additional analysis in order to check whether the order of familiarization presentation (individual chase first vs. Coordination first) affected participants' looking behaviour. However, a 2x2 ANOVA with order of familiarization presentation as between-subjects factor and outcome (sharing vs not sharing) as within-subjects factor did not yield a significant interaction between order of presentation and outcome (F (2, 46)=0.2, p=0.65), not confirming this hypothesis.

Therefore, these results could have two possible interpretations:

a) The individual chasing action introduce or invoke the goal concept of catching the prey during familiarization facilitated the cooperative interaction as serving the shared goal of catching the prey during the test phase. This would suggest that coordination and joint action in a different domain (moving the obstacles) could still produce the expectation of sharing over a different goal (attributed to them later). This might mean that infants inferred a type of long-term cooperative relationship between the agents, where the reward does not have to be in the very same context as where the joint efforts were originally invested.

b) Adding the individual chase information has transformed the interpretation of the coordinative joint action as having the goal to move the obstacles away from remaining isolated and unconnected to the chasing events (which involved a different goal). The two goal-directed actions could become linked through a sub-goal – final-goal structure, where pushing away the obstacle and thereby unblocking the passage way satisfied an enabling sub-goal that contributed to the individual chaser's success to catch the prey (final-goal), and therefore produced the expectation of sharing. This would suggest that infants expected sharing when the joint actions were interpreted within the same goal context as the final goal of catching the prey. This hypothesis was not confirm by the additional analysis exploring whether the order of familiarization movies presentation affected infants expectations. Nevertheless, it remains a genuine possibility.

2.8 Experiment 6. Default expectations for resource distribution: the case of individual chasing

Data collection was started in 2020 but disrupted due to global Covid-19 pandemic.

Even though we have already addressed the question of default expectations for resource distribution in Experiment 2 (see section 2.4), which did not produce a positive result, one possibility is that infants, similar to Experiment 4, were failing to assign a goal to the actions of the agents in the familiarization, and the chasing goal was presented only later in test trials, preventing them from forming an expectation about resource distribution even if otherwise they would. In order to control for this possibility we designed a control experiment, presenting infants with chasing pattern in the familiarization but not demonstrating any cooperative or competitive interaction. This was achieved by presenting individual chase pattern involving one chaser and one evader.

2.7.1 Participants

Participants tested so far were seventeen full-term 13-month-old infants (7 females, mean age = 13 months 12 days, range 13 m 6 d to 13 m 26 d). Five additional infants were excluded from the final sample: three due to fussiness and two for reaching the maximum looking time in two trials or more.

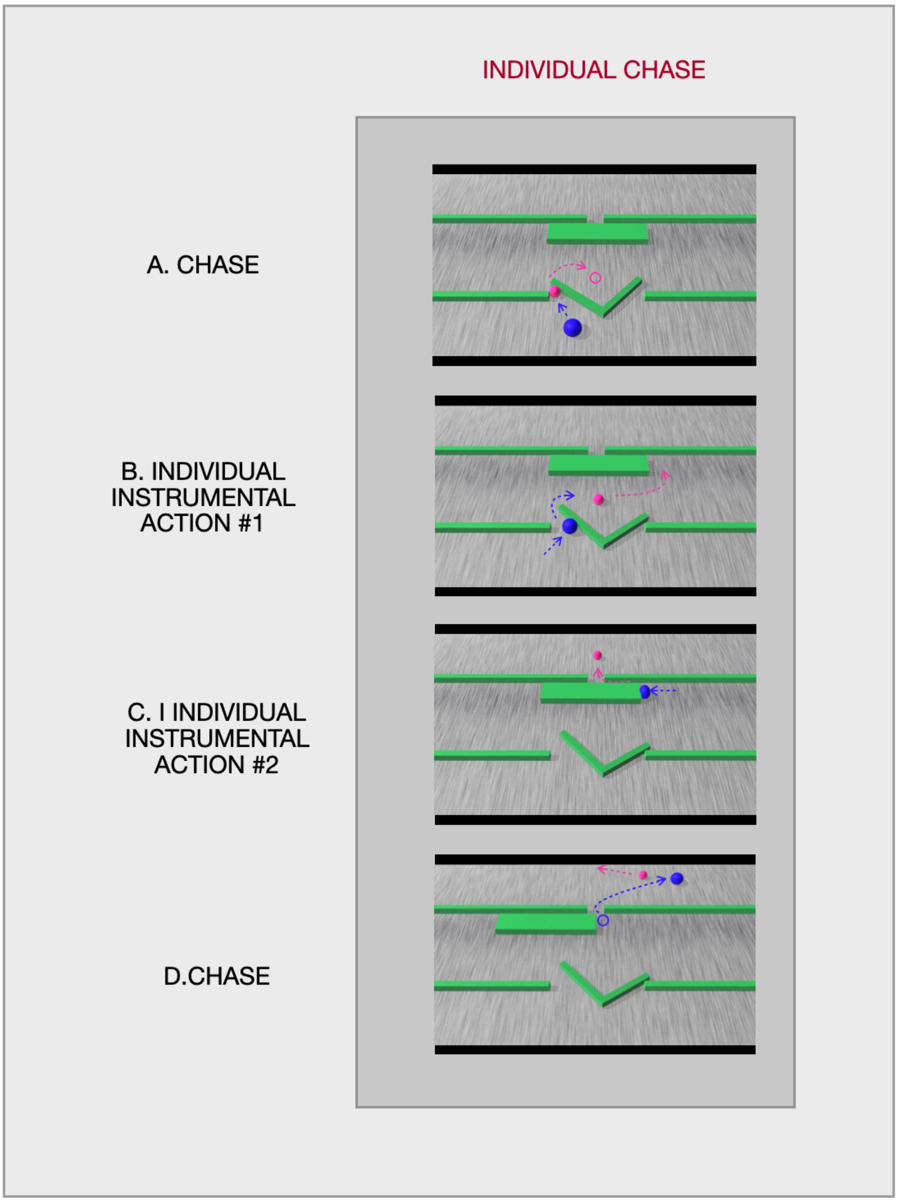

Figure 10. Familiarization trials timeline in Experiment 7. Familiarization trials started with one blue chasing the pink ball (A). The chaser moved away the obstacle alone and continued the chase (B). The evader escaped through the small opening; the chaser moved the second obstacle (C). Agents left the screen continuing the chase (D).

2.7.2 Stimuli

Familiarization Trials

Familiarization movies depicted an individual chase pattern: there was only one chaser and one chasee present. The setup of the obstacles was identical to the previous familiarization trials in Experiments 3-5. The only difference was that only chaser was presented and performed all the instrumental actions of moving away the obstacles on its own. This way, goal-directed chasing action was present, but cues of cooperation of competition were absent. If infants failed to form expectations for resource distribution due to inability to attribute goal to the agents in the familiarization in Experiment 2 (or even even fail to represent them as agents), then such goal priming with individual chase in the familiarization should aid them in doing so in current experiment.

Test trials

After the familiarization each participant saw 4 test movies. The test trials were identical to those used in the previous experiments.

2.9 Discussion

The present studies addressed four basic questions:

1) Are infants able to differentiate and recognize patterns of cooperative vs. competitive interactions of goal-pursuit?;

2) Can infants rely on this categorisation of interactive events to make differential predictions about the expectable resource sharing behaviours of the participating agents?

3) Is there a basic default preference infants attribute to agents for either sharing or not sharing resources independently and in the absence of previous engagement in cooperative or competitive interactions and investment of efforts to obtain the resources?

4) Are infants' differential expectations about resource sharing induced by the types of interactive behavioral patterns (coordination vs hindering) exhibited by the agents or are such expectations a function of the kind of goal context (shared versus individual goal pursuit) attributed to such (cooperative versus competitive) patterns of interactions (e. g., cooperative chase vs competitive chase)?

In Experiment 1 and 3 during familiarization each infant was exposed to one of two sets of behavioural cues by interacting goal-directed agents. For one group these cues (e.g. mutual action coordination and joint goal pursuit) were indicative of a cooperative chasing pattern aimed at jointly achieving a shared goal (to catch the chasee). In contrast, the cues presented to the other group (e.g. individual goal-pursuit plus actions aimed at hindering the pursuit of the same goal by a rival agent) suggested competition over the same goal that was simultaneously but separately pursued by two competing agents as their individual goal. During the test phase each group saw two alternative event outcomes: in both test events the goal has been first reached (the chasee was caught) which was followed by either of two alternative (equal of unequal) resource distribution events (sharing or not sharing the "prey").

We hypothesized that if infants are sensitive to the fact that the likely distribution of the resource outcome (sharing versus not sharing) is a function of the kind of interaction (cooperative vs competitive) and effort that the interactive agents engage in to acquire the goal, then they will make different inferences about the agents' expectable sharing behaviour. Namely, the sharing outcome should be consistent with joint and coordinated efforts, as the cooperative partners are expected to be equally rewarded for the coordinated work and equal effort the invested in achieving their shared goal, while not sharing the outcome is predicted by the achievement of an individual goal by one of the agent, which is in line with the competitive attitude exhibited by the rival agents toward each other, and their attempts to hinder one another in acquiring the single goal of catching the prey.

Consistent with these predictions, infants showed differential looking at the test events after having been familiarized with either cooperative or competitive patterns of chasing interactions. Infants reacted with longer looking at test scenarios in which cooperative interactions were followed by no sharing of the joint goal outcome. Thus, they linked cooperation with an expectation of equal distribution of the gained resources. In contrast, when the agents engaged in competitive patterns of interactions, infants expected them not to share the outcome.

This result was replicated in Experiment 3 using a different set of cues (joint instrumental actions vs individual instrumental actions). Replicating the findings of Experiment 1 with a different set of cues was important in order to demonstrate the reliability of the effect and to ensure that the differential patterns of looking time was not due to low-level stimuli differences in the conditions. This indicates infants' flexibility in being able to interpret a variety of different cues as suggestive of cooperative interactions in various contexts. In fact, in-and-of-themselves none of the cooperative cues we used would have necessarily been interpreted as coding cooperation if presented in alternative contexts. E.g. the two individual agents' coordinative actions could be interpreted as efficient (in so far as they contributed to maximizing the cooperative agents' joint efficiency) only if infants assigned a shared goal to the interacting partners. Considering the same actions performed by either individual agent in the context of attributing the same outcome to the agent as his individual goal, their actions would cease to be the most efficient alternative to achieve the goal on their own. Similarly, the cue of stopping and waiting for another agent to arrive at a designated place before initiating a simultaneous approach of the chasee would be interpreted as an inefficient action if performed by a single goal-pursuing agent (as it would involve unnecessarily stopping the pursuit of the goal in spite of the absence of an obstacle blocking the way to approach it). Not so, however, if the infants assigned to the agents a shared goal (as well as shared knowledge of pursuing a common goal together) in which case the two agents would be expected to coordinate and adjust their joint behaviours to the environmental constraints so as to maximize their joint utility and follow up on their joint commitment to pursue the shared goal together.

One could object, however, that the expectation of sharing demonstrated in Experiment 1 and Experiment 3 could simply reflect a general default expectation made by human infants about equal resource distribution among social agents. For example, such a general default attitude to share resources among group members could be expected on the basis of the proposal of a core domain of 'social beings' (Spelke, 2016) where similarily of fearures and behaviors indicate group membership that would predict an affiliative expectation of sharing among members of the same group. Additionally, infants of similar age expect equal distribution of resources by third parties (e.g., Geraci & Surian, 2011). In order to control for the possibility of a default preference account for either sharing or not sharing, we ran Experiment 2 where

		Familiarization	Results
Experiment 1	**Cooperative chase**	Various cues of cooperation: joint efficiency, waiting, turn-taking	Expect agents to share
	Competitive chase	Various cues of competition: hindering the rival, individual efficiency, asynchrony	Expect agents NOT to share
Experiment 2	**Control: no interaction, no chasee**	Interpretation of the scene in terms of chasing was blocked: no chasee, independent motion	No expectation
Experiment 3	**Cooperative chase: joint action**	Joint instrumental actions: moving obstacles together and coordinated chasing	Expect agents to share
	Competitive chase: individual actions	Individual instrumental actions; moving obstacles alone; hindering each other in chase	Expect agents NOT to share
Experiment 4	**Coordination (no chasee)**	No chasee, moving obstacles in coordinated fashion	No expectation
	Hindering (no chasee)	No chasee, moving obstacles individually; hindering	No expectation
Experiment 5	**Coordination 2: all information is available but not integrated**	Fam #1: no chasee, coordinating in moving the obstacles. Fam #2: individual chase	Expect agents to share
Experiment 6	**Control: individual chase**	Individual chase; individual instrumental actions: moving obstacles alone	Unfinished

Table 1. Summary of the experiments presented in Chapter 2.

we provided no cues of cooperation or competition during familiarization but we tested infants' expectations of resource sharing using the same test conditions as in the other experiments. In spite of the featural similarity of the agents (blue spheres) observed during familiarization, the results confirmed that in the absence of information about cooperative or competitive efforts invested during previous interactions between the agents to obtain the goal, infants do not generate differential expectations about the agents' subsequent sharing behaviour, as indicated by similar looking times at sharing vs not-sharing outcomes during the test events.

In sum, infants' expectations suggest that relying on context-dependent cues of goal attribution (shared versus individual goals) infants are able to flexibly interpret the different set of cues and patterns of interactions as cooperative (or competitive) by recognizing and attributing shared goals and mutual knowledge to the cooperatively interacting agents in the presented scenarios.

These results then led us to the question of whether infants' expectations for resource sharing is induced by the recognition of interactive behavioural cues (such as mutual coordination) that are indicative of cooperation. Alternatively, such cues are not sufficient in-and-of themselves to induce an attitude for resource sharing and the goal context is necessary for infants to categorize the interactive patterns as indicating a cooperative versus a competitive interaction. Within the goal context the different kinds of interactive patterns are interpreted as being justified by attributing a shared goal versus an individual goal to the participating agents. This may be a precondition to generate differential expectations about sharing or not sharing the goal outcome. In other words: is it a precondition for expecting sharing the prey that the agents cooperatively chased it together? Or is it the coordination between the partners that induced the expectation of sharing?

One possibility is that the different expectations about resource distribution demonstrated in our first set of studies were induced by the minimal cues of movement synchronicity or antagonistic hindering actions between the agents (without the attribution of a common or competing goal to these patterns of interactions), and not the higher-level interpretations of them as cooperative or competitive goal-pursuit. Previous studies suggest that infants at the age of 20 months take into account the valence of agents' previous actions (helping or hindering) and expect agents to be rewarded accordingly (Surian and Franchin, 2017). Although in our studies agents shared the reward between themselves, potentially infants could assign a positive valence to cooperating individuals and a negative value to competing agents and expect the differential sharing pattern based on the valence values attributed to the agents. Alternatively, a valence could be assigned to the interaction between the agents: cooperating would be assigned a positively valence while competitive interactions would be represented with a negative valence. Then the differential expectation about sharing versus not sharing respources would be due to the positive valence (predicting sharing) or the negative valence (predicting not sharing) attributed to the types of interactions. In both cases the the goal of chasing itself would be irrelevant for generating these expectations.

In order to explore this question in Experiment 4 we removed the chasee from the familiarization phase. Now, instead of chasing the ‘prey’, the two agents were synchronizing their actions in order to move obstacles out of their way, or - as in the case with the competitive scenario - were performing individual actions of moving obstacles asynchronously, while also hindering the competitor in his attempt to remove the obstacle. In this case we did not find the same expectations of resource distribution, suggesting that minimal cues of coordination or rivalry is not enough to set up expectations about resource distribution. This finding does not support the hypothesis that associating positive or negative values with different patterns of interactions could lead to different expectations about resource sharing at the age of 13 months. It is possible though that such inferences become established later in development (as suggested by Surian and Franchin's study in which the infants were 20 months of age).

However, there could be an additional factor contributing to the absence of expectations about differential sharing in our study, namely, the difficulty to inferentially bridge the time gap between the familiarization events and the goal information presented only later during the test phase. The goal of catching the prey was not available during processing the patterns of interactions observed during familiarization, and it may have been difficult for the young infants to attribute the goal of catching the prey retrospectively to justify the different types of interactive patterns as cooperative or competitive chasing of the shared or individual goal of catching the prey. This, however, would have been necessary to serve as the basis of generating different expectations of resource sharing during the test phase.

In Experiment 5 we explored this possibility by trying to facilitate the attribution of the goal of chasing to the interactive patterns by priming the concept of the goal of chasing a prey already during the familiarization phase through adding an extra event depicting an individual chasing action to the familiarization events. This manipulation proved to be successful: the availability of the goal concept of chasing already during familiarization appears to have allowed infants to justify the patterns of interactions in terms of the goal of chasing interpreting them as cooperative versus competitive chasing of the prey as a shared or an individual goal, respectively. This is indicated by the finding of differential looking at sharing versus not sharing the prey during the test phase replicating the pattern of results of Experiments 1 and 3.

Overall, based on the current results we suggest that infants' understanding of social goals (e.g. helping: Kuhlmeier et al 2003; giving: Tatone and Csibra, 2015) can therefore also induce inferences about resource distribution based on the type of interaction in question. It is not only that infants are able to recognise patterns of interactions of cooperation and competition (akin to helping and hindering), but they can go go beyond this information to make particular inferences about how the agents involved in this type of interaction would behave if the interaction contributed to a later acquired benefit.

Chapter 3. Does cooperation promote agent individuation and re-identification?

3.1. Introduction

In the previous chapter we explored and provided evidence for the proposal that humans possess dedicated cognitive mechanism to identify and differentiate cooperative and competitive interactions and make inferences about resource distribution based on the type of interaction. In particular, we demonstrated that infants expect cooperating agents to share the benefits they achieved in their joint venture, in contrast to competitive context where infants held the opposite expectation.

However, engagement in coordinated collaborative interactions provide not only immediate advantages (such as sharing of the resources gained in a joint venture), but can also lead to significant and long lasting fitness benefit for the agents belonging to a social community who routinely engage in a variety of collaborative ventures. Such benefits include distribution of resources between long-term cooperative partners over time, even when a partner in question did not participate in all of the ventures for resource acquisition. These interactions are based on delayed reciprocation and are beneficial under the conditions of asynchronous acquisition of resources, typical for human ecological niche.

In order to successfully realize and maintain the capacity to organize such joint cooperative activities within a social group presupposes the availability of cognitive competences that allow to track multiple cooperative partners and their contributions to the common pool of resource exchange.

3.1.1 Cognitive adaptations supporting cooperative partner choice

In this chapter we shall focus on the availability in early ontogeny of a crucial adaptation that equips infants with specialized mechanisms that support person-specific encoding. Such mechanisms, on the one hand, are necessary to support individuation, and identity tracking of the particular agents participating in the cooperative ventures. On the other hand, these mechanisms must also be responsible for identifying and monitoring person-specific performance: exhibited skills and competences of particular cooperative partners, as well as their contribution to the common ventures.

These capacities are necessary to support informational basis for selection of competent and trustworthy individuals as cooperative partners to team up with, as well as to avoid individuals represented as lacking such relevant properties.

In this chapter we explore the question to what degree (if at all) these complex prerequisites are present in the scope of the early capacities of young infants, who may at first only be able to perform simple recognition and identification of individual agents who are as participating in particular cooperative interactions (or not).

3.1.2 Reciprocal altruism and bookkeeping systems in humans and other species

One influential evolutionary model to account for the emergence and selection for prosocial motivations to engage in altruistic behaviors (e.g. the propensity of sharing resources) is based on the idea of reciprocal altruism (Trivers, 1971). This theoretical approach suggests that engaging in locally altruistic actions can be beneficial for the donor if it ensures reciprocation of his investment by the recipient’s complementary action in the future to return the benefit received from the donor. Such reciprocal exchange of favors and resources could provide the basis for sustaining long-term mutually beneficial relationships with non-kin social partners, which is a signature property of human cooperation.

For reciprocal altruism to emerge, several preconditions are required to be in place in order to stabilize mutually beneficial cooperative exchanges. One of these preconditions is the ability to detect cheating in order to recognize and prevent free-riding behaviors. This in turn requires a specialized bookkeeping system to track and register the investments of individual participants during particular collaborative interactions as well as across the history of multiple cooperative ventures (Cosmides and Tooby, 2005). If an imbalance of investment is detected, the monitoring agent can either use punishment to control the free-rider partner's behavior and ensure his future cooperation or suspend the collaboration, exclude the cheating participant from the cooperative relationship and substitute him by selecting a new cooperative partner.

Below we shall briefly review the available evidence indicating the presence of such an elaborate bookkeeping system in humans for monitoring individual cooperative partners and tracking their investments in the domain of collaborative social interactions, and discuss its differences from the kind of bookkeeping systems found in other primate species. We shall also address the various arguments proposed to account for why such a sophisticated bookkeeping system has evolved and played an essential role in humans but not in other species. We argue that the ability to track individual cooperative partners and their investments contributed to joint activities over time is a key functional component of the "cooperative package" of specialized adaptive mechanisms in humans. This package of dedicated cognitive competences had been selected to serve humans' species-unique adaptation for engaging in complex collaborative ventures to jointly pursue and achieve shared goals, which yielded mutually advantageous outcomes. These functionally related cognitive adaptations are likely to have co-evolved under the particular selective pressures that characterized the ancestral environment in which early human social groups must have survived.

Some forms of specific bookkeeping systems are present in a number of group-living primates (Seyfarth & Cheney, 2012). Given and received services are closely matched in exchanged quantity in the particular relationships among non-kin partners (Jaeggi & Gurven, 2013), although, unlike in humans, these activities tend to be restricted to domain-specific service exchange such as grooming (de Waal, 1997) and does not include exchange of resources. Another difference between human and non-human bookkeeping systems is that primates rely mostly on long-term partnerships and do not seem to modify their interactive behavior as a function of relevant changes in their partner's performance during the recent history of cooperative acts (e.g., food sharing: Jaeggi et al., 2012; joint actions: Melis, Hare & Tomasello, 2006).

Such simple score-based bookkeeping systems can be easily exploited by individuals underinvesting by a margin without being detected as a cheater (Gilby, 2012). This at the same time also indicates that the kind of coarse score-based exchange registration system non-human primates possess is sufficient to satisfy the required maintenance of reciprocity of exchange they typically perform, as it has not been selected against despite the possibility of systematic exploitation. It has been suggested that one of the reasons for that is that the act that benefits the other involves very small costs for the actor and therefore affords being discounted even if not reciprocated. In this view, the system that only allows to detect accumulated underinvestment in long-term relationships is sufficient for maintaining such low-cost exchange practices: choosing partners based on their general readiness to cooperate might be a better strategy than detecting and avoiding being cheated occasionally (Aureli, 2012; Schino & Aureli, 2009).

For maintaining the type of long-term collaborative social activities characteristic of humans, however, such simple systems of bookkeeping could not suffice. Even though in some types of relationships there is a seeming imbalance of investment (Schiefenhövel, 2014), this usually happens in long-term reciprocal cooperative relationships with trusted partners where it can be accepted or overlooked to maintain the valuable relationship over a longer period of time (Shackleford & Buss, 1996). It does not happen due to an inability to detect the imbalances (as it is the case with other species), but rather due to strategic reasons to tolerate such imbalances because of the delayed nature of reciprocation that characterize human cooperative relationships. Additionally, such an attitude may also serve a specific signaling function - by tolerating imbalances partners can indirectly communicate their trust in future reciprocation (Barclay, 2013).

However, humans typically participate in a variety of cooperative relationships, and not all of them are long-term or involve trusted partners. In short-term partnerships where delayed reciprocation is unlikely or impossible, detailed bookkeeping and immediate reciprocity are required to prevent free-riding and ensure that the interaction is mutually beneficial.

In fact, the ethnological literature on traditional hunter-gatherers suggest that humans are able to sustain even long-term relationships based on precise tracking of material exchange: the practices of gift-giving and debt-relationships in the Masaai and Turkana in Eastern Africa are remarkable examples of this kind (Bollig, 2010). Gurven (2004) reports that the amount of received goods has been found to be contingent on the amount of given goods in the exchange practices in those groups where this ratio has been estimated (e.g. Hiwi, Ache, Yanomamo, Aka, Hadza). The contingency here is estimated as the correlation between the amount of goods that A gives to B and B gives to A over a sample period of time (ranging from several weeks to several months).

There is also ample anecdotal support for contingent exchange matching coming from different ethnographic sources. Aspelin (1979) was told by one of his Maimanfe informant that "if one doesn't give, one doesn't get in return . . . some people are specifically excluded from most distributions because they never or only rarely give any of their products to us". Myers (1988) describes that among the Pintupi people in Australia who hunt kangaroos "large game is distributed inter-domestically to members of the residential group who have shared with the hunter in the past".

The evidence reviewed above suggests that humans' bookkeeping systems are qualitatively different from those present in other species, as they allow for fine-grained investment tracking over a long period of time, as well as flexible adjustment depending on the type and length of the cooperative relationship.

Jaeggi and Gurven (2013) proposed that these more sophisticated systems have developed under the selective pressure of the unique ecological and social factors that characterized of our ancestors' social environment: interactions between risky foraging partners with unpredictable returns, asynchronous resource acquisition and high dependence on cooperative partners who differ in their abilities and willingness to invest effort in common ventures (Kaplan et al, 2012). Uneven resource acquisition by different members of a social group provided selective pressure for sharing resources to flatten food provision over time: those who were lucky today in possession of large amount of food could provide it to others at a low cost, and expect in return to be reciprocated later when themselves would be in need (Kaplan & Hill, 1995).

The necessity to interact with multiple partners in order to obtain food, while those partners differed in their skills and motivations created a pressure to distinguish and keep track of the partners and their investment, as well as reciprocate selectively with the best of them to secure their partnership for the most beneficial cooperations.

3.1.3 Selection pressure for cooperative partner choice

As discussed in previous chapters, the human disposition to cooperate has been proposed to developed under the selective pressure for collaborative partner choice (Baumard, Andre and Sperber, 2013). In order to participate in cooperative activities one has to be accepted as a reliable and skillful cooperative partner by other members of the social group.

Potential partners for joint collaborative ventures differ in their individual skills, in the amount of effort they are able or willing to invest and their degree of motivation to incur costs during cooperative joint activities. The selective pressure should favor, on one hand, traits that facilitate successful cooperative activities, and on the other hand, mechanisms that allow for effective partner selection. A minimal condition for such a system to work is the ability to recognize and track the identity of particular cooperative partners. Moreover, given the potential costs and benefits involved in optimal partner choice, the processing costs allocated for identity tracking might be increased in cooperative settings when compared to other contexts in which partner selection is not relevant or less consequential.

Tracking the identity of cooperative partners and registering their performance and cooperation-relevant properties is especially important as it provides the informational basis to guide choices of high quality cooperative partners for new interactions or to engage in similar cooperative interactions with reliably prosocial partners and to avoid unreliable ones.

Given the importance of efficient partner selection and pressure for attracting cooperative partners for long-term interactions, humans should possess a cognitive mechanism for both investment-tracking and means to associate investments in joint activities to particular agents.

Such representations of individual agents must be accessible and retrievable from memory to enable the re-identification of the individual.

If the specialized mechanism dedicated to identify and individuate particular collaborative agents is indeed an evolutionarily selected cognitive adaptation, it is plausible that it's basic structural components would be accessible and could be manifested to function already during early ontogeny. We hypothesize that this specialized capacity may be adaptive and can be demonstrated already in early infancy, even before human infants' motor development would enable them to actively participate in mutual cooperative activities themselves and provide them with relevant first-person experience of mutual cooperative interactions.

In particular, we propose that early access to the mechanism of agent individuation and tracking could play an adaptive role by enabling young infants to recognize, attend to, and learn about different aspects of cooperative interactions observed from a third-party perspective. This would provide them with highly useful observational learning opportunities to differentiate and encode various types of collaborative activities, complementary role structures, or patterns of resource allocation. Such learning opportunities would represent a developmentally significant advantage by preparing infants to become increasingly skillful and knowledgeable cooperators by the time they are mature enough to start actively engaging in collaborative activities themselves.

3.1.4 Infants' ability to individuate, track, and re-identify individuals

Humans perceive the world in terms of separate physical objects and agents that persist through time. One ability that allows us to do it is tracking objects spatiotemporally - when your fork falls under the table you know it did not disappear even if you do not see it. You know you will find it there, lying on the floor. Another way to track the objects is based on the particular features of an object: if you reach for your fork under the table but find a spoon instead you would be surprised and assume it is another object and your fork is still there (or it's magic). But when and how do these capacities emerge in the development?

Feature-based object identification tends to appear significantly later than identification based on spatiotemporal criteria (Xu and Carey, 1996). For example, already 3-month-olds are able to detect violations of spatiotemporal continuity, when an object disappears behind one screen and reappears from behind another non-adjecent screen, without appearing in the gap between them (Aguilar & Baillargeon, 1999; Luo & Baillargeon, 2005), or when a moving object appears on the other side of a solid wall, apparently passing through it (violating the solidity principle, Spelke et al, 1992). However, infants at this age do not show surprise in a change-detection task in which a stationary object is covered by an occluder or a container and when it is removed to reveal the object again, the reappearing object's perceptual properties, such as its shape, colour or size, have been transformed (Wilcox, 1999; Hespos & Baillargeon, 2001b). Baillargeon et al. (2009) suggested that young infants under 1 year of age are not yet able to integrate the visible featural properties (such as color, size, shape) in their representations of physical objects.

In order to succeed in the change-detection task described above, infants have to represent the identity-relevant featural information about the object, maintain this representation during the occlusion event, and compare it with the newly emerging object upon the removal of the occluder. If the object does not move after it has been occluded (but remains behind the occluder), it’s spatio-temporal parameters do not change, so upon it’s reappearance infants can rely only on featural criteria to detect whether the identity of the object has been changed or not.

In fact, even 12-months old infants do not individuate object based solely on surface features yet. In a series of experiment Xu et al (2004) presented infants with two objects that differed either in color only, or only in size, or in a combination of size, color, and pattern, or only in shape in an object individuation paradigm. During familiarization the two objects appeared from behind a screen always one at a time: coming out of occlusion and then returning back behind the screen again sequentially so that any given time only one of them was visible. In the test phase the screen was removed revealing either one or two objects behind it. Since there was no spatiotemporal discontinuity between the objects’ movement paths during familiarization, infants could only individuate them as different based on the differences of their visible features, and therefore they could infer the number of objects behind the screen based on featural information only. The results showed that infants at this age succeeded in establishing a representation of two distinct objects only when given information about shape differences (although even then they only succeeded when the shape differences were representative of a kind difference (e.g. cup vs bottle) and not when the change of shape did not change object kind (e.g. when two different shaped cups appeared).

However, it has also been demonstrated that the ability of infants to individuate objects based on featural criteria can be boosted under some circumstances. Xu (2002) showed that infants are able to individuate two objects even at the age of 9 months, if they are verbally labeled ("Look, a duck!" vs "Look, a ball!"), and Bonatti et al (2002) demonstrated the success at 10 months of age without labeling, but only when the objects presented differed in terms of animacy (an agent vs an inanimate object). Futo et al (2010) demonstrated that when infants were presented with two novel spatiotemporally separated objects were also shown to have two different functions, 10-months old infants inferred that two objects were present.

Communicative interaction involving object labelling (Xu, 2002) or ostensive pedagogical demonstration of object function (Futo et al, 2010) can boost infants' object individuation.

Furthermore, agents involved in social interaction might be encoded better. In a study by Rochat, Striano and Morgan (2004) 5-month-olds detected a change when agents changed roles in a chasing scenario, which they could only do by encoding the individuals. Similarly, Tatone and Csibra (2015) demonstrated that 12-months old infants encoded agents' identity in a giving interaction (however, not in the taking interaction). Another piece of evidence, supporting the suggestion that interacting agents might be better encoded come from the adult literature: individuals facing each other (which suggests social interaction) are better re-identified than those who face away from each other (Vestner et al, 2019). Importantly, participants in this study did not have a task of remembering those individuals, and the recollection was incidental, reminiscent of how the infants are being tested.

Taking these findings into account, we hypothesize that cooperative interactions pursuing a shared goal will boost infants' encoding of features necessary to track the identity of particular agents.

3.1.5 The current studies

Above we have argued that tracking the identity of agents involved in cooperation is more relevant and necessary than just tracking the identity of other – non-cooperative - agents. Differentiating between agents involved in cooperation in contrast to those that are not, as well as individuating, encoding and tracking particular cooperative partners and selectively attend to their cooperative investments and motivational dispositions would provide relevant information for other agents in their social group when selecting partners for later collaborative ventures.

We hypothesized, therefore, that observing collaborative interactions in a cooperative context would differentially trigger and enhance processes of feature-based agent individuation, leading to encoding and tracking the identity of individual agents supporting their successful re-identification even in young infants (even though feature-based agent individuation may require extra processing resources). In the set of studies we present below we test the hypothesis that young infants are able to track the feature-based identity of agents involved in a cooperative interaction to achieve a shared goal, while they maybe yet unable to do so if the agents observed are not involved in cooperation.

In order to find out whether infants encoded information that makes the collaborative agents re-identifiable, we applied a paradigm exploiting a change detection procedure. Change-detection is a well-established paradigm widely used in infants for investigating the processes involved in encoding, tracking and re-identifying individual objects (see examples below). This paradigm reveals the presence of certain representations by contrasting two conditions: after a target object is occluded for short interval either the same (no change) or a featurally different object (change of object) is revealed. Infants' detection of changes of an individual objects' properties (e.g. a change of its features) will lead to an increase in looking time that serves as an index of violation-of expectation. If there is a difference in looking times between the feature-change and no-feature-change conditions, it is an indication that infants detected the change of identity of the object, and therefore were able to individuate the agent and track its identity by encoding its perceptual features.

We have carried out three experiments with 13-month-old infants. The first study (Experiment 7) aimed to tests our hypothesis that infants are able to track the identity of cooperative partners. In order to operationalize cooperative agency and interaction we build on our previous studies discussed in Chapter 2 and used the same familiarization stimulus event as in Experiment 3 involving cooperative chasing by two agents, as these stimuli have already proven successful in inducing recognition of cooperative agents in infants of the same age.

At the tested age, however, infants can already perform feature-based identification of individual objects, so the predicted results of Experiment 7 may obtain even if cues of cooperative agency are not present. With Experiment 8 we intended to exclude this possibility. Experiment 9 aimed to test whether cues of chasing in themselves without a cooperative context are sufficient to induce feature-based agent identification.

3. 2. Experiment 7: Tracking the identity of cooperative agents

3.2.1 Participants

Participants were twenty full-term 13-month-old infants (11 females, mean age = 13 months 13 days, range 13 m 0 d to 13 m 25 d) from Hungarian-speaking families from larger Budapest area, with no visual or hearing problems. Seven infants were excluded from the final sample: five due to fussiness, one for equipment failure and one for experimenter's error. Parents signed an informed consent before taking part in the study, and all participants received a small toy as a gift for their participation. This research complied with relevant ethical regulations and was approved by the Hungarian Ethical Review Committee for Research in Psychology (EPKEB).

3.2.2 Procedure

Infants were tested in a quiet, dimly lit room, approximately 1 m away from the computer monitor. They sat on their caregivers' laps. The caregivers wore darkened glasses, so that they could not see the stimuli. They were instructed not to interact with the child in any verbal or non-verbal manner. Furthermore, if the infant turned completely away from the stimulus for more than 5s, the caregiver was instructed to turn him back in the initial position facing the screen. This procedure ensured that infants could freely turn away when they were not interested in the display but could be reoriented for a next trial without interfering with the measurements.

Infants saw 4 familiarization movies followed by 4 test trial movies. Familiarization movies presenting cooperative and competitive scenes were administered between subject. Each participant saw 2 test movies depicting the “change" condition vs. 2 of the “no change” condition in ABAB order. Half of the infants saw the “change" outcome first, and half - “no change” outcome first. The last frame of each test movie remained still on the screen until the infant looked away for more than 2 consecutive seconds, or else looked at the screen for more than 30 cumulative seconds.

The experiment was ran on an Apple Mac Pro Quad Core 2.8 computer, controlled by PsyScope X (Cohen, MacWhinney, Flatt, & Provost, 1993). The stimuli appeared on a 24-inch TFT screen.

The experimenter monitored infants via the camera placed above the screen from a separate room. The recordings were further analyzed offline.

3.2.3 Stimuli

Familiarization trials

Familiarization trials in this experiment were identical to Experiment 3, Joint Action condition described in the previous chapter. We will briefly describe it here.

Familiarization movies consisted of 3D animations depicting three spherical agents moving on a grey surface. Two bigger agents, the "chasers", were of the same size and blue colour, and the chasee was a pink-coloured ball, approximately 30% smaller: 3°5' and 2°3’ in visual angle for blue and pink balls respectively.

The scene depicted two types of obstacles positioned horizontally on the stage. Each wall had a large opening. The access to this opening, however, was prevented by large objects of different shape. There was a large V shape object preventing access to the exit in the first (more proximal) wall, then a large rectangular object preventing access to the exit in the second (more distant) wall (fig.5). In order to follow the chasee, chasers had to move the obstacles from their way .

The interpretation of the event as chasing was ensured by incorporating two of the strongest cues identified by previous research to induce in infants the impression of a goal-directed chasing action (Frankenhuis et al, 2013): acceleration and attraction ("heat-seeking"): chasers pursued the chasee in a "heat-seeking" manner with sudden directional changes with speed acceleration towards the chasee. Furthermore, chasers motion was in accordance with joint efficiency rather than individual efficiency: each chaser acted taking into account the movements of the partner (for example, helping to decrease the distance between the chasee and the partner, even if it increased its own distance from the chasee).

Each familiarization trial lasted 20 seconds.

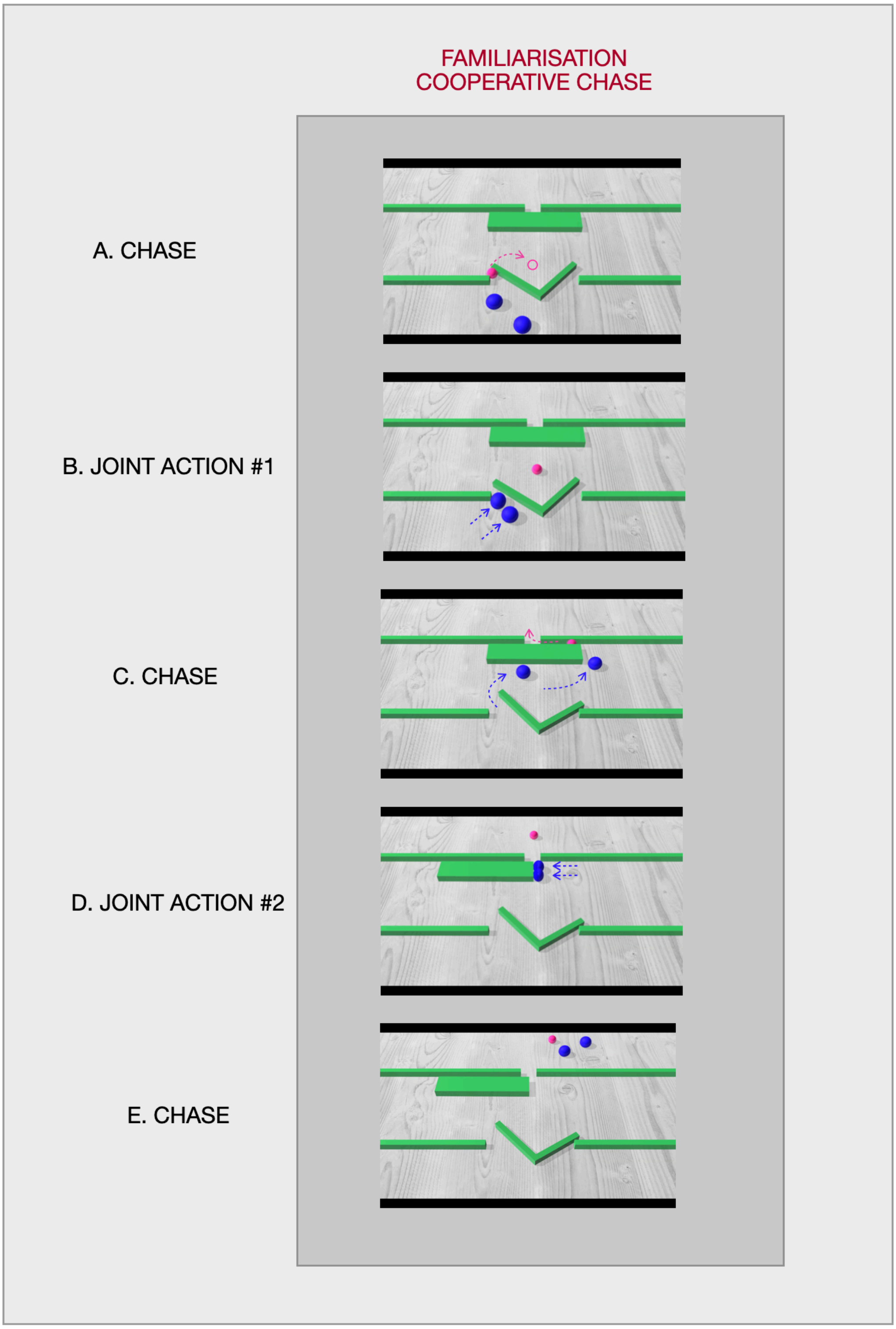

Figure 11. Familiarization trials timeline in Experiment 7. Familiarization trials started with the two blue balls chasing a pink ball. The chasee goes through the small opening, but chasers cannot fit through (A). Chasers move away the obstacle in a coordinated joint fashion and go through the opening (B). The evader escapes through the small opening to the other side (C); chasers jointly move away the obstacle (D). Agents leave the screen continuing the chase (E).

Test trials

After the familiarization each participant saw 4 test movies, each 7 seconds long. The test trials depicted a short initial chase (3 seconds, fig. 12A), after which two agents - one chaser and one chasee - left the screen (it took them another 2 seconds), while the second chaser went behind the occluder (seemingly continuing the chase), fig. 12B. After two other agents left the scene, the occlusion continued for 2 seconds, then occluder went up (fig. 12C), revealing either the same agent (round and blue), or perceptually different (yellow cone), see fig. 12D. This results in a static scene where looking time was measured. The static scene was on the screen till infants reached timeout criteria.

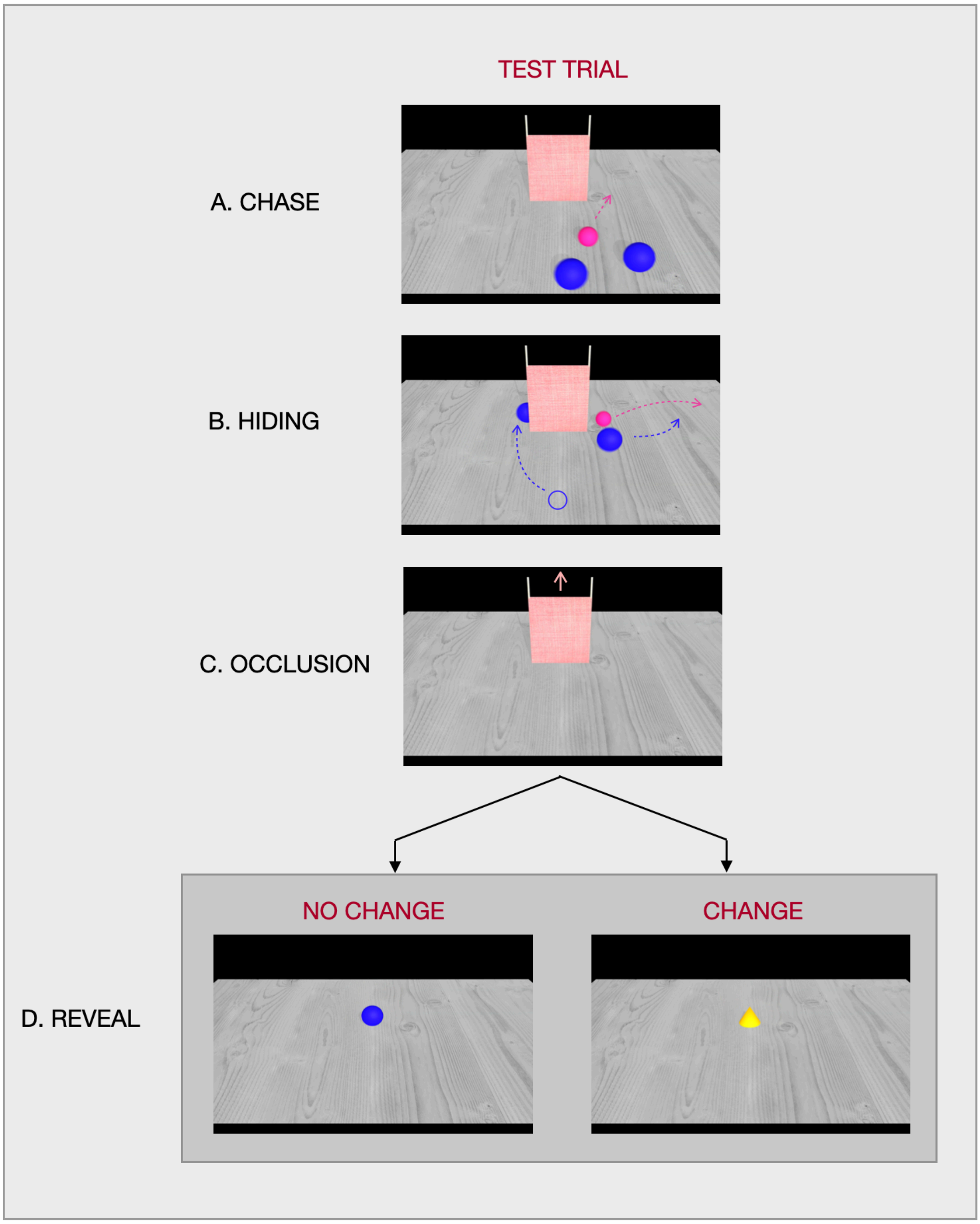

Figure 12. Test trials timeline in Experiments 7 and 8. Test trials starts with the two blue balls continuing to chase the pink ball (A). One of the chasers go behind the occluder while chasing; the second chaser and the chasee go outside the scene (B). The first chaser stays behind the occluder for 2 sec (C). The occluder is lifted; either the original agent or a different agent is revealed behind it. Looking time is measured (D).

3.2.4 Results

Half of the participants (10 infants) was randomly selected and coded by the second coder. The inter-coder agreement was high, with correlational coefficient of 0.95.

Looking time analysis (ANOVA with condition as within-subjects factor) showed that infants were surprised if the agent behind the occluder was different from the original as indicated by longer looking times ($M_{NoChange}$=7.14 s, SD=3.51s vs. M_{Change}=11.01 s, SD=7.31s, F(1, 19)=8.48 p=.008, η^2p=.3). At the individual level 14 out of 20 infants looked in the predicted direction (p=.057, binomial test), confirming the pattern. This difference suggests that infants tracked the identity of the cooperative chasers.

We have performed an additional analysis in order to check whether the order of test presentation (change trials first vs. no change trials first) affected participants' looking behaviour. A 2x2 ANOVA with order of presentation (Change vs No change) as between-subjects factor and outcome (same agent vs different agent) as within- subjects factor did not yield a significant interaction between order of presentation and outcome (F (1, 18)=1.23, p=0.6).

The effect also showed to be persistent: we have checked whether the looking time pattern changed over the course of test trials and was different in the first two trials from the last two test trials. 2x2 ANOVA with block of trials (first two trials vs last two trials) as between-subjects factor, outcome (change vs no change) as within- subjects factor, showed no significant interaction ((F (1, 36)=2.6, p=.11; η^2p=.06), suggesting that the infants' expectations did not change over the test phase.

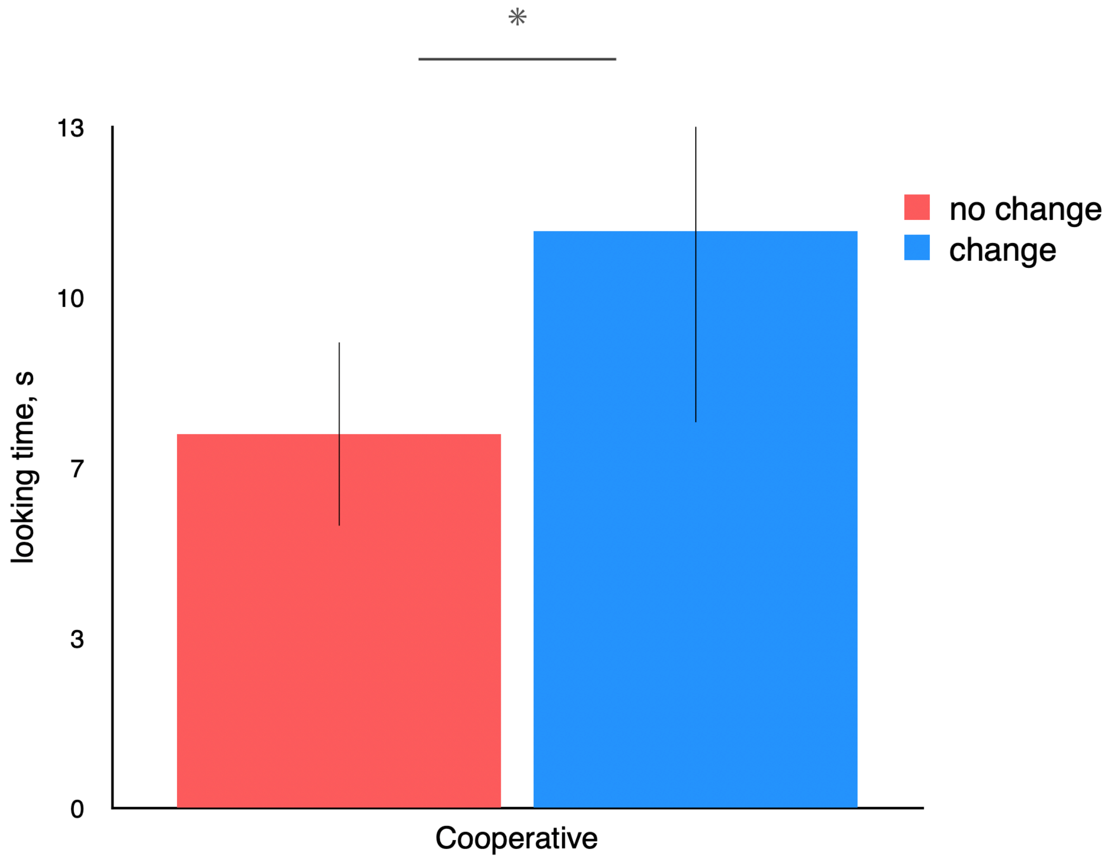

Figure 13. Mean looking times in case of same (no change) or different (change) agent outcome in Experiment 7, after infants saw cooperative chase during the familiarization. Infants were surprised if a different agent appeared after occlusion as indicated by their looking times. Error bars represent standard deviations.

While the looking time pattern measured in this experiment is congruent with the hypothesis that we advanced in the introduction we do not know whether this result was caused by the presence of the cooperative interaction or whether infants could track the identity of the agents otherwise. In order to investigate this issue we tested two additional groups: in Experiment 8 we removed both the cooperative and chasing pattern, while in Experiment 9 we preserved the chasing pattern but removed the cooperation (by testing feature-based agent identification in the case of a single chaser). We then compared the results of the two control groups with that of the current cooperative chasing experiment.

3.3 Experiment 8: Tracking the identity of non-cooperative agents

3.3.1 Participants

Participants were twenty full-term 13-month-old infants (17 females, mean age = 13 months 13 days, range 13 m 00 d to 13 m 28 d) from Hungarian-speaking families, with no visual or hearing problems.

Six additional infants were excluded from the final sample: four due to fussiness and two for reaching the maximum looking time in two trials or more. Parents signed an informed consent before taking part in the study, and all participants received a small toy as a gift for their participation. This research complied with relevant ethical regulations and was approved by the Hungarian Ethical Review Committee for Research in Psychology (EPKEB).

Procedure

The procedure was identical to Experiment 7.

3.3.2 Stimuli

Familiarization trials

Familiarization trials in non-cooperative condition depicted the same three agents performing perceptually closely matched actions. However, the chasing, as well cooperative patterns were removed from the scenes: all agents moved independently in different part of the screen and never interacted with one another in any way.

The animations largely consisted of the same types of movements and trajectories as in the previous study, but cut and put in different order as well as moved along the "Z" axis (e.g. a chasing movement that an agent was performing in the upper part of the screen in the last 5 seconds of an animation would be performed in the lower part of the screen in the beginning of a movie and not following an evader but independently). This strategy ensured that even though the familiarization movies were closely matched to the cooperative condition in low-level perceptual properties (the amount and pattern of agents' movements) while any interaction between the agents was eliminated. We assumed that an interpretation of the events as "cooperative chase" was unlikely.

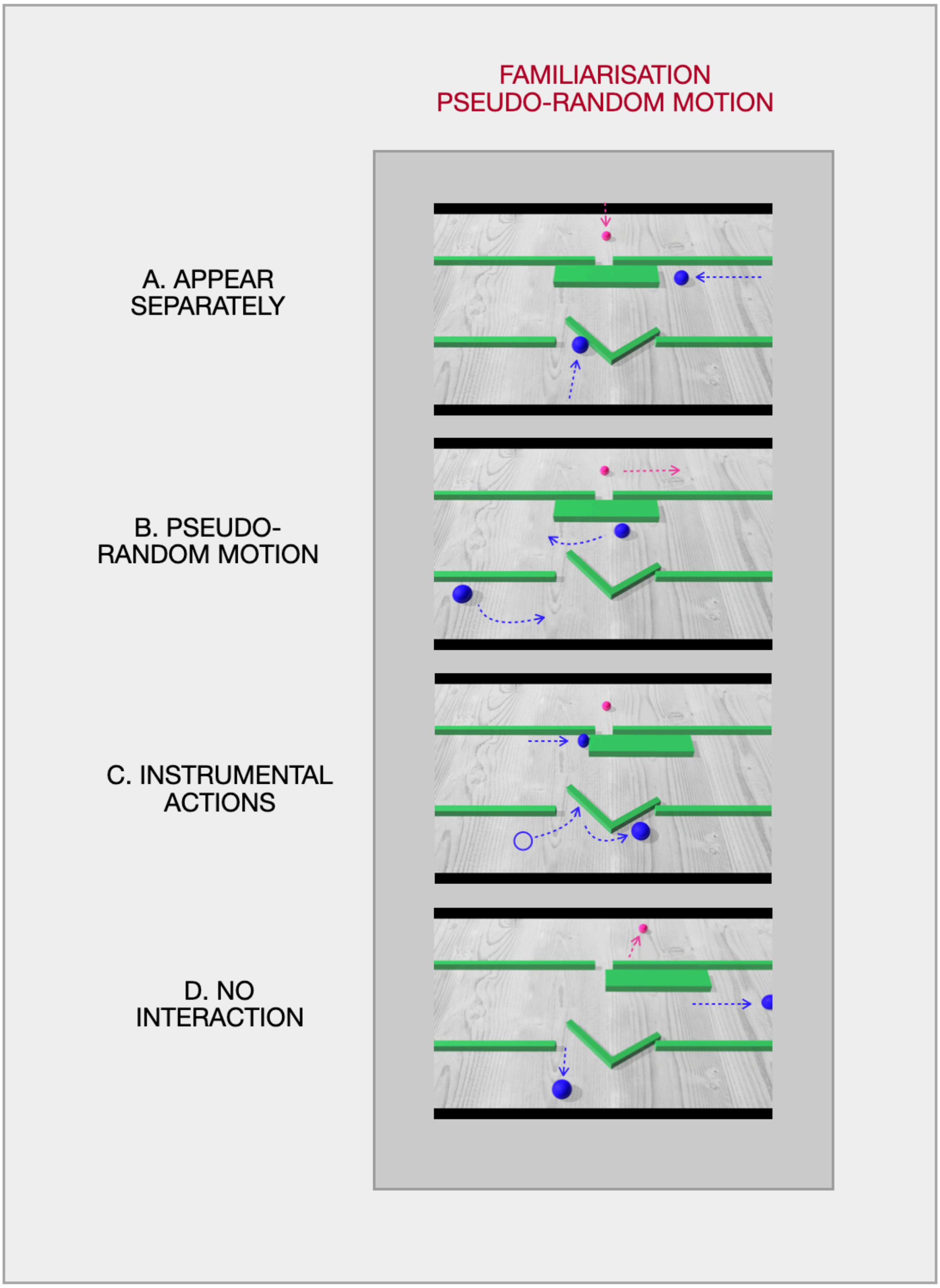

Figure 14. Familiarization trials timeline in Experiment 8. 1. Familiarization trials started with the two blue and one pink ball entering the scene from different sides (A). All agents performed the amount movement matched to Experiment 7 (cooperative) (B). Blue agents also performed instrumental actions of moving the obstacles, each moving one. They did not go on the other side, instead staying in the same part of the scene (C). Agents left the screen the same way they entered. They never interacted with one another (D).

Familiarization trials started with agent entering the scene, but unlike in cooperative study, each agent entered separately: one large blue ball ("chaser" in the previous study) appeared at the lower edge of the screen, identical to the previous study; another blue ball (second "chaser" in the previous condition) entered from the side of the screen (left and right was counterbalanced across trials), while the smaller pink ball ("chasee" in the previous study) entered the scene from the upper edge of the screen (with the same speed and trajectory as leaving the scene in the cooperative condition but played backwards), see fig. 14A.

After entering the scene each agent performed a series of actions. These actions where visually closely matched to the actions presented in the stimuli of the previous study on a variety of factors: the speed, the motion trajectories and the amount of movements. The events, however, were unfolding in different order at different location. By implementing this solution, we expected that the scene and the relation between the protagonists cannot be captured in terms of cooperation. For example, blue balls bumped and moved the obstacles like in the familiarization movies in the previous study, but did so independently of each other and at different points in time. An important feature of these animations was the each agent was separated from the other two by the obstacles, and stayed in the same part of the screen (upper, middle, or lower) during the entire duration of the scene (fig 14B,C). The scenes ended with agents leaving it independently at different locations (similar to entering the scene) (fig 14D).

Test trials

Test trials were identical to Experiment 7.

3.3.3 Results

Looking time was calculated based on off-line coding. Half of the participants (10 infants) was randomly selected and coded by the second coder. The inter-coder agreement was high, with correlational coefficient of 0.93.

Looking time analysis showed that infants looking time did not differ significantly depending on whether they saw the same or new agent after the occluder went down ($M_{NoChange}$=6.77s, SD=3.29 vs. M_{Change}=6.93s, SD=3.01, F(1, 19) = 1.25, p=0.8, $\eta^2 p$= 0.06). This result suggests that infants did not individuate the protagonist agent.

In a 2x2 ANOVA with condition (cooperative vs non-cooperative) as between-subjects factor, outcome (change vs no change) as within- subjects factor, and participants as a random factor yielded a significant interaction between condition and outcome (F (1, 38)=4.45, p=.04, $\eta^2 p$=.12), suggesting that the infants' were detecting change of the agent better as a function of cooperative pattern of interaction agents were involved in.

3.4 Experiment 9: Tracking identity of an individual agent

One possible alternative explanation of the results in Experiment 7 is that infants pay more attention to chasing pattern, and therefore can individuate the participating agents better. Infants are extremely sensitive to chasing scenario starting at least 6 months of age (Frankenhuis et al, 2013).

In order to test this possibility we carried out another study. Familiarization trials in study 3 were similar to Experiment 7 (Cooperative condition), however, instead of two chaser agents there was only one. This way, we preserved the chasing pattern but removed the cooperative interaction.

3.4.1 Participants

Participants were twenty full-term 13-month-old infants (13 females, mean age = 13 months 10 days, range 13 m 03 d to 13 m 29 d) from Hungarian-speaking families, with no visual or hearing problems.

Two additional infants were excluded from the final sample: one due to fussiness and one due to the equipment failure. Parents signed an informed consent before taking part in the study, and all participants received a small toy as a gift for their participation. This research complied with relevant ethical regulations and was approved by the Hungarian Ethical Review Committee for Research in Psychology (EPKEB).

Procedure

The procedure was identical to Experiments 7 and 8.

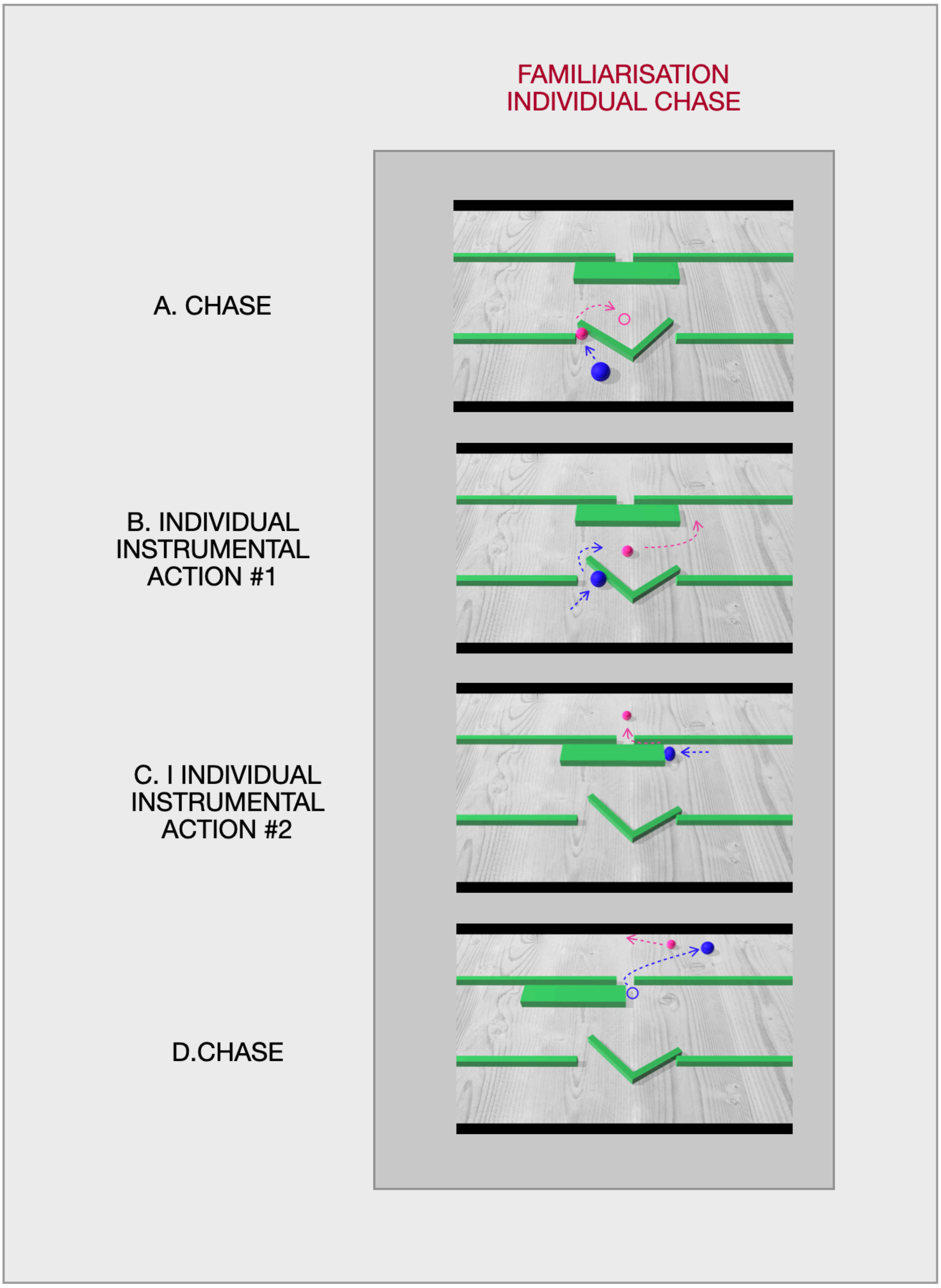

Figure 15. Familiarization trials timeline in Experiment 8. 1. Familiarization trials started with one blue chasing the pink ball (A). The chaser moved away the obstacle alone and continued the chase (B). The evader escaped through the small opening; the chaser moved the second obstacle (C). Agents left the screen continuing the chase (D).

3.4.2 Stimuli

Familiarization trials

Familiarization trials were similar to those in Experiment 7 (cooperative chase), but instead of two big blue balls ("chasers") there was only one following the smalle pink agent ("chasee"). The trajectory of the "chaser" was an average of the two blue agent from Experiment 7. The blue agent also moved both obstacles alone (fig. 15).

The movements of the "chasee" and the obstacles were identical to those in Experiment 7.

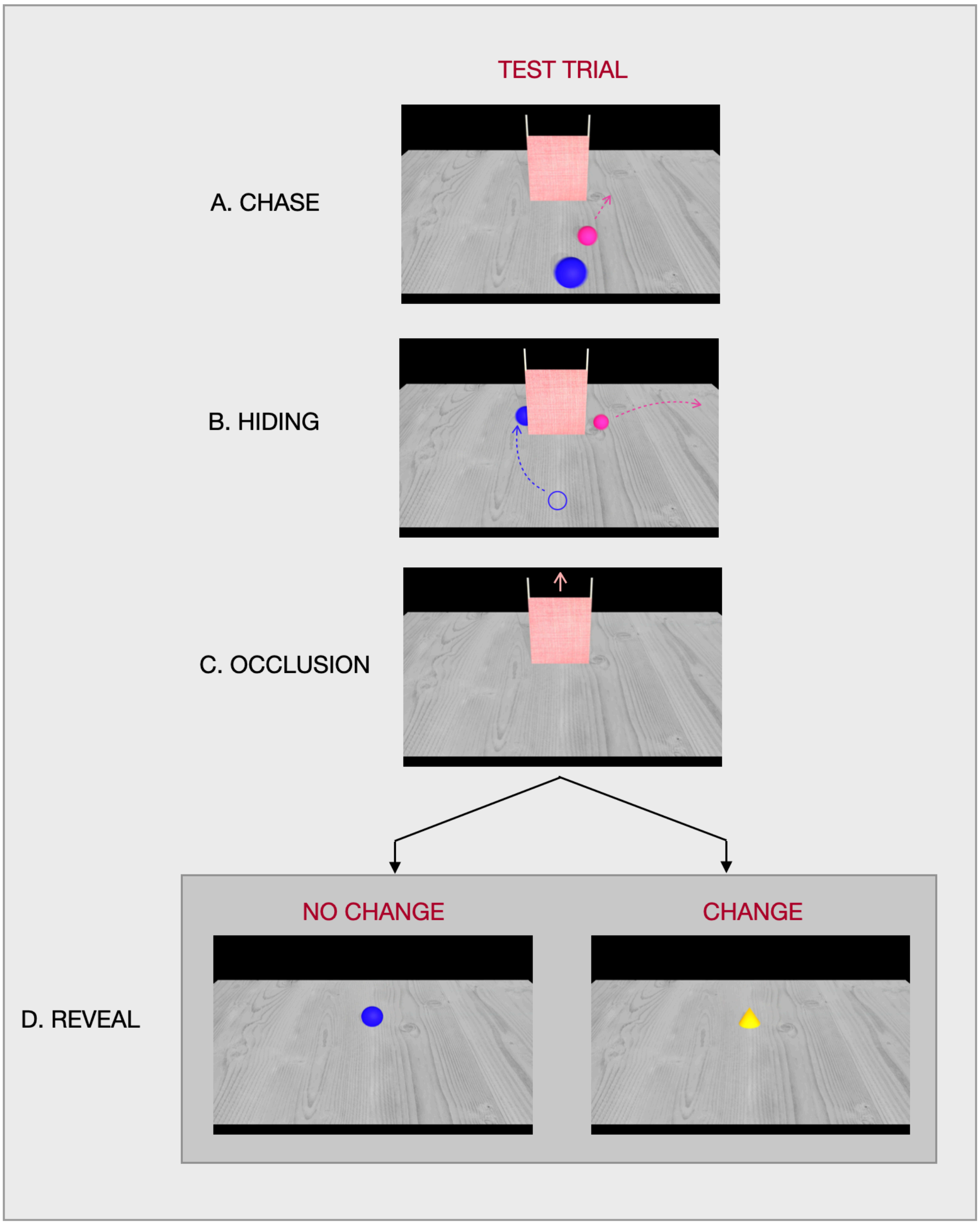

Figure 16. Test trials timeline in Experiments 8. Test trials starts with the blue ball continuing to chase the pink ball (A). The chaser went behind the occluder while chasing; the chasee went outside the scene (B). The chaser stayed behind the occluder for 2 sec (C). The occluder lifted; either the original agent or a different agent was revealed behind it. Looking time measured (D).

Test trials

Test trials were similar to Experiment 7 and 8, with the exception that only one chasee was present. Short initial chase (2 sec, fig. 16A), the chasee left the scene, and the chaser went behind the occluder (fig. 16B). The rest of the movie follower test trials from the previous experiments (fig. 16C,D).

3.4.3 Results

Twenty 13-months old infants were included in the final sample and analyzed. Looking time was calculated based on off-line coding. Half of the participants (10 infants) was randomly selected and coded by the second coder. The inter-coder agreement was high, with correlational coefficient of 95%.

Looking time analysis showed that infants were not surprised if the agent behind the occluder was different from the original as indicated by similar looking times ($M_{NoChange}$=7.479 s, SD=4.98 vs. M_{Change}=6.001 s, SD=2.589, F(1, 19)=3.25; p=0.089, η^2p=.14).

This result suggests that similar to Experiment 8 infants did not differentiate between the old and the new agents.

In a 2x2 ANOVA with condition (cooperative vs individual) as between-subjects factor, outcome (change vs no change) as within- subjects factor, and participants as a random factor yielded a significant interaction between condition and outcome (F (1, 38)=9.11, p=.004, η^2p=.19), suggesting that it is not the chasing pattern promoting re-identification of the agents (as chasing is present in both groups) but the cooperation.

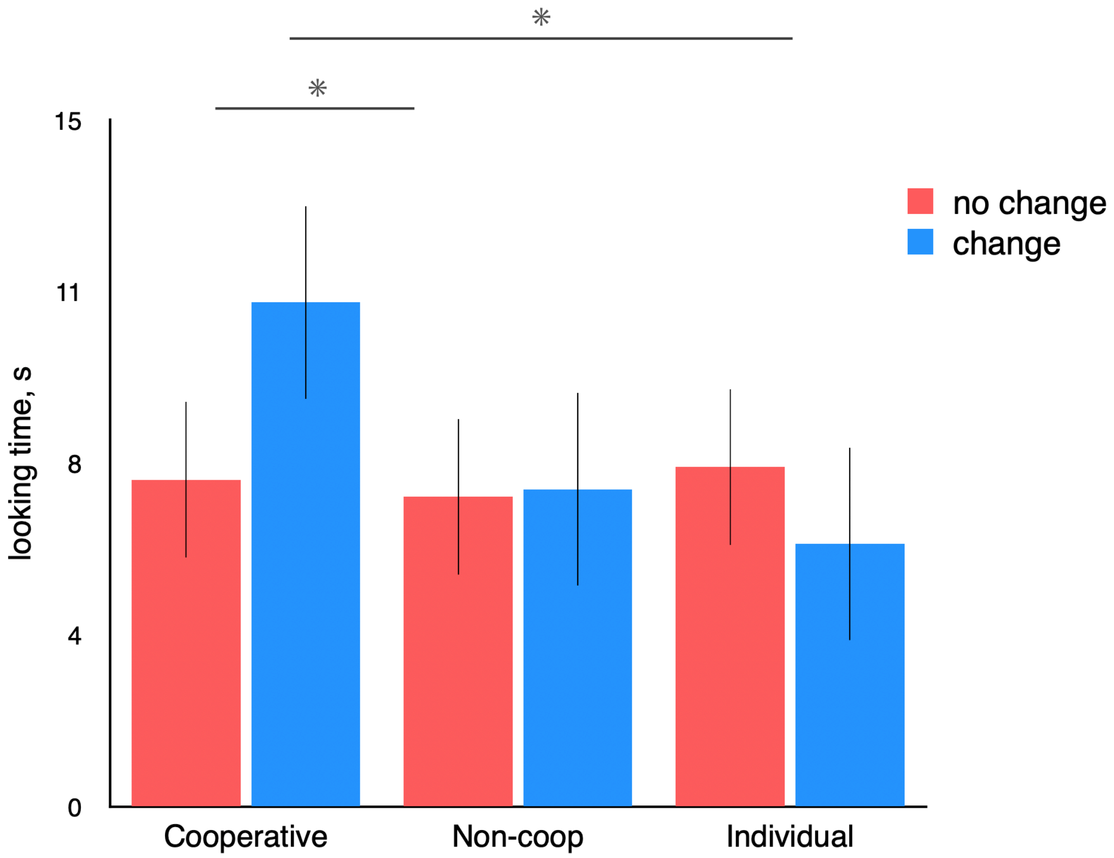

Figure 17. Mean looking times in case of same or different agent outcome ("no change" vs "change") in Experiments 7-9. Cooperative Chase group result is significantly different from both Non-cooperative Agent group and Individual Chase group, suggesting that it was the presence of cooperative pattern that allowed infants to individuate the agent.

3.5 Discussion

The main aim of the studies reported in this chapter was to test the hypothesis that young 13-month-old infants possess and can apply in cooperative contexts the key mechanism for feature-based agent identification, identity tracking and re-identification. We hypothesized that if infants already possess an evolved mechanism for assessing cooperative interactions, the recognition of cooperative agents should induce and facilitate their ability for feature-based agent identification and identity tracking even though this process requires extra processing resources. In particular, such selective activation of feature-based agent identification should be expected to be triggered to a lesser degree in a situation that involves non-cooperative agents where agent identification may be based on spatio-temporal criteria only. This predicts differential performance showing successful feature-based agent identification in the case of the cooperative agents in contrast to non-cooperative agents in 13-month-olds.

We presented 13-month-old infants with video-animations depicting one of the following scenarios:

1) *Cooperative Chase*: two cooperative agents coordinating their actions to jointly achieve a shared goal involving a cooperative chasing scenario with two balls chasing a third smaller ball in a coordinated fashion (presenting several cooperative cues such as simultaneously performing joint instrumental actions to remove obstacles in order to be able to follow chasing the escaping chasee);
2) *Non-Cooperative Agents: Pseudo-random motion.* Two balls performing pseudo-random actions which were closely matched in perceptual low-level features with

the cooperative chasers' movements performed in 1) but which lacked any cues indicating either cooperative interaction or a goal-directed pattern of chasing the third, smaller object;

3) *Non-cooperative Chasing: Individual agent's goal-directed chasing.* An individual agent involved in an efficient goal-pursuit (chasing to catch the escaping chasee). This stimulus event therefore preserved the goal-directed pattern of efficiently chasing a chasee but lacked any cues of cooperative interaction as there was only a single (and so necessarily non-cooperative) chaser present in the chasing event.

After being familiarized to one of the alternative scenarios above, during the test phase infants in all three groups were presented with a change-detection task: one of the protagonist "chaser" agents went behind the occluder, and after a short temporary occlusion it either reappeared without changing its features (same identity) or another agent with different features emerged (change of identity).

Infants seem to have encoded and represented the feature-based identity of the cooperative agents in Experiment 7 as they found a perceptually different agent reappearing at the same location surprising (showing increased looking), but did not show such a violation-of-expectation response (no increase in looking times) in either of the control conditions that did not provide cues of cooperative agency during familiarization.

Consistently with our hypothesis, these results indicate that exposure to a cooperative pattern of goal-directed joint interaction selectively triggered and facilitated infants' ability for feature-based agent individuation resulting in encoding, tracking and successful re-identification of the individual coopatative agents. Thus, the specialized mechanisms for agent individuation and identity tracking that are necessary for monitoring and re-identifying individual cooperative agents (which forms a precondition for accessing relevant information about them for later partner choice) are present and selectively triggered at an early age in human infants.

Importantly, recognizing that an agent is involved in a cooperative interaction has a similar facilitating effect on feature-based individuation and identity encoding across a variety of cooperative action contexts (apart from cooperative chasing events): for example in communicative ostensive labelling of novel objects (Xu, 2002), communicative function demonstration of unfamiliar artefacts (Futó et al, 2010), or ostensively demonstrating objects belonging to different categories (Bonatti et al, 2002). This is also in line with the results of Tatone and Csibra (2015) who showed that 12-month-old infants succeed in feature-based encoding of the identity of agents who participated in a ‘giving interaction’ (both giver and givee), but did not do so for agents engaged in a ‘taking interaction’. The authors suggested that ‘giving’ is interpreted by young infants as a social interaction that involves the prosocial transfer of the possession of an object, while taking is perceived as an individual instrumental goal-directed act. In the case of giving, similarly to the case of cooperation, the social interaction involves investment and prosocial benefit between two specific agents and entails mutual expectation of reciprocity and return of benefit in the future. Hence, it is relevant to encode the individual agent who benefited his specific interactive partner in order to maintain successful bookkeeping of welfare balance and represent the selective expectation of future reciprocation from the particular recipient who received the benefit donated in order to maintain a long-term and mutually beneficial relationship.

An open question for future research is whether such an effect of facilitated individuation serving later re-identification is limited to agents involved in cooperative relationships, or more broadly applies to other social interactions as well. For instance, would infants track the identity of competitors just as readily? If an agent is actively hindering another agent it might be advantageous to remember the particular hindering individual. However, the hypothesis about cooperation and identification presupposes that an individual has multiple experiences with cooperative partners. Evolutionary speaking the most extreme cases of competitions are likely to be with members from other groups and the possibility for repeated interactions and encounters are probably less abundant, hence building profiles of competitors may be less beneficial. On the other hand, if competition is an intra-group affair than encoding of particular competitive individuals would be valuable for adjusting partner choice, in particularin order to avoid future interactions with these individuals.

One possibility to explore this question would be to present infants with the stimuli we developed for the studies reported in the previous chapter, but depicting a competitive pattern of interaction ("Competitive Chase"). If infants are indeed sensitive to patterns of rivalry and hindering then encoding and tracking the identity of such individuals would be beneficial, and we should see a looking pattern similar to the Cooperating Agents condition in present studies: namely, infants would show surprise and longer looking times if a featurally different agent would emerge after the previous agent's temporary occlusion. A more refined prediction would be that infants may encode the identity of outgroup competitors better than they do in case of ingroup members.

Similar questions can be asked about other types of social interactions. If indeed infants preferentially encode cooperating individuals for reasons of potential partner choice, this should not be the case for other types of prosocial interactions that do not assume welfare balance. In particular, parent-child interactions (and possibly other types of social relationships belonging to the domain of "communal sharing" - see Fiske, 1992), which are inherently asymmetric may not require investment tracking as this kind of information would be irrelevant for maintaining such asymmetric social interactions and relationships (where children are the permanent recipients of investment and are not expected to reciprocate). While cooperation between "equals" assumes tracking the investments of particular agents as relevant for future welfare balancing, this is not the case with types of interactions that involve communal sharing. E.g. if presented with mother-child type of interactions (e.g. as in Spoke & Spelke, 2017), the encoding of identity of the particular agents involved may not be similarly facilitated as in reciprocal social interactions as this type of inherently asymmetrical social relationship is not characterized by mutual reciprocity and therefore does not require person-specific bookkeeping to stabilize long-term welfare in the social group.

Chapter 4. Infants expect others to cooperate

with Katarina Begus, Günther Knoblich, György Gergely and Arianna Curioni

4.1 Introduction

4.1.1 Human's intrinsic motivation to cooperate

The last key element of cooperation we are going to consider is uniquely human motivation to cooperate.

As we discussed in General Introduction, not only do humans start engaging in cooperative activities early in development (Warneken, Gräfenhain & Tomasello, 2012), it also seems that the prosocial behaviour is intrinsically motivated and truly has the goal of improving the situation of the recipient (and not other indirect benefits such reputation management): infants help other even when the recipients do not know they are being helped (Hepach et al, 2017b), external rewards and encouragement do not improve prosocial behaviours, and sometimes even diminish it(Warneken and Tomasello, 2008; Ulber et al, 2016), and infants are equally satisfied and others are being helped by third parties as by themselves (Hepach et al, 2012).

Some evidence suggests that this motivation is also present for engaging in joint actions with others. In a comparative study, Rekers and the colleagues (2011) presented chimpanzees and 3-year-old children with the task where they could get their rewards (either food or toys) by either performing an individual action - pulling a rope alone - or a joint action - pulling a rope together with a conspecific. While chimpanzees chose at random, children were much more likely to choose the collaborative option, even though they were slower at retrieving the rewards when collaborating. Thus, children show a preference to engage with collaborative partners to pursue a goal together even in situations where cooperation is neither necessary nor the most efficient action alternative available to achieve their goal. In contrast, chimpanzees seem to be strictly instrumental with their collaboration - when in the later follow-up Bullinger et al (2011a) doubled the reward for the collaborative pulling, chimpanzees chose it most of the time.

Further, Warneken et al (2006) presented chimpanzees and 18-months-old with four different collaborative tasks: two instrumental (with the reward to be gained at the end), and two non-instrumental - cooperative games. While chimpanzees engaged only the instrumental tasks, infants were just equally likely to do both instrumental tasks and games. Simply the fact that children engage in collaborative tasks with virtually any friendly adult is telling, while to make chimpanzees perform tasks jointly one has to carefully choose partners who are tolerant and not aggressive towards each other (Melis et al, 2006).

Unlike other great apes, and similarly to new world monkeys, humans evolved as cooperative foragers and breeders for whom acting together with conspecifics provides an essential survival benefit. By cooperating in a variety of domains, humans can achieve highly valuable goals that would be otherwise unavailable. The survival advantage that resulted from the social interdependence of humans in foraging and the necessity to flexibly and quickly engage in cooperative activities may have constituted a crucial pressure for the evolution and selection of cognitive and motivational mechanisms reinforcing a preference for cooperation (Tomasello et al, 2012). It has been proposed that the increasing complexity and scale of human cooperation necessitated the cooperative abilities to emerge earlier in the development, allowing more time for the development of skills necessary for individuals to become proficient cooperators by adulthood, and thereby increasing their fitness (Tomasello & Gonzales - Cabrera, 2017). It has been also proposed that human infants' cooperative and communicative abilities have evolved in the context of cooperative breeding, prevalent in human groups (Hrdy, 2009; Hawkes, 2014). As cooperative child-rearing allowed women to have more closely spaced offspring and to distribute and share caregiving tasks with other caregivers, infants faced the new challenge of competing with siblings and other children for the attention of multiple caregivers. Infants who could better understand and predict the behaviour of the adults could also solicit their help and attention more successfully. This may have constituted a significant evolutionary pressure for the early onset of social cognition, communication and various cooperative skills in humans (Hermann et al., 2007).

However, even when it is not crucial to act together for achieving a given goal, it might still be beneficial to do so: first, frequent and spontaneous engagement in cooperative activities supports the acquisition and developmental mastery of a variety of relevant cooperative skills allowing them to become skillful cooperators. Second, if social agents frequently engage in cooperative activities with different partners, they might gain opportunities to learn about their relevant cooperative skills, as well as dispositional traits essential for successful cooperation such as commitment, trustworthiness and propensity for fair resource distribution. Through dedicated cognitive mechanisms, individuals can retain such relevant person-specific knowledge, making it accessible to support optimal partner choice for future cooperative ventures.

Therefore, the necessity to flexibly and quickly engage in cooperative activities may have constituted a crucial pressure for the evolution and selection of cognitive and motivational mechanisms reinforcing a preference for cooperation (Tomasello et al, 2012; Tomasello & Gonzales - Cabrera, 2017). Importantly, if such a preference for cooperation is indeed a result of cognitive evolutionary adaptations, it might be detectable early in ontogeny. Here, we seek evidence that such dedicated cognitive and motivational mechanisms, which allocate an inherent reward value to cooperative activities, guide infants' expectations already at 14 months of age.

4.1.2 Infants' sensitivity to rationality and utility of actions

We hypothesize that if humans have dedicated cognitive and motivational mechanisms supporting the propensity to cooperate (Hermann et al., 2007), even young infants, whose ability to engage in cooperative activities is still limited, may hold expectations about other agents' preferences for cooperative activities. Thus the aim of the current studies was to investigate whether 14 month old infants expect agents to cooperate.

To address this question, we took advantage of infants' early sensitivity to the rationality and utility of goal-directed actions (Gergely & Csibra, 2003; Jara-Ettinger et al., 2016; Liu et al., 2017). Even before their first birthday, human infants have been shown capable of understanding goals and preferences of other agents by applying and combining a number of informative sources available to them, such as intentions (Woodward et al, 1998), mental states (Gergely et al., 1995, Onishi et al., 2005, Luo & Baillargeon, 2007, Luo & Johnson, 2009) and physical properties (Saxe et al., 2006). Most importantly, infants apply a 'teleological stance' to observed actions (Gergely & Csibra, 2003), that is an action interpretation system implementing the basic assumption that agents will choose the most efficient means available to achieve their goals. As early as at 3 months of age, infants are able to predict an agent's goal by assuming she would achieve it by incurring minimal costs (Skerry et al., 2013, Liu et al., 2019), and 9-month-old infants do not attribute goals to agents whose actions unfold inefficiently (Hernik & Southgate, 2012; Southgate & Csibra, 2009). The Naive Utility Calculus (Jara-Ettinger et al., 2015) provides a recent computational implementation of the teleological stance. According to this model, one can not only predict an agent's choice based on the relative costs of the action alternatives available to the agent, but also quantify the agent's preference for a given goal, based on how costly is the action performed to achieve it. Experimental work has provided evidence that infants indeed seem to apply these principles when interpreting others' actions. In action observation paradigms, 6-month-old infants expected agents to minimize the costs of their actions, and 10-month-old infants inferred an agent's preference between two goals, based on the costs they incurred to achieve each of them (Liu et al., 2017; Liu et al., 2017). Capitalising on infants' precocious abilities to infer agents' goals and preferences based on observed actions, we applied the naïve utility calculus model to test infants expectations about cooperative joint actions, i.e. actions in which two agents coordinate in space and time to jointly bring about a change in the environment (Sebanz, Bekkering, & Knoblich, 2006).

Cooperative joint actions integrate the principles of goal directed and instrumental actions - operationalized in terms of costs and rewards - with cooperation and action coordination between two or more agents. On the hypothesis that infants expect agents to be individual utility maximizers, their naive utility calculus may operate independently by evaluating the separate action utilities of the two agents when engaged in a joint action. This would result in their cost-reward analysis of cooperative activities equating to the sum of the instrumental utilities of the two separate actions. In contrast, if infants expect agents' behavior to be guided by a preference to engage in cooperation as opposed to individual actions, they may ascribe additional reward value to cooperative activities. Consequently, their cost-reward computations in joint action scenarios could not be reduced to the sum of costs and rewards of two agents' instrumental actions.

4.1.3 The current studies

We tested 14-month-old infants, who have already been shown to be able to calculate the combined costs of actions (distances travelled) that two agents perform in a joint activity and showed an expectation that the agents will minimise their combined cost (Mascaro & Csibra, 2014). In our studies, we presented two groups of infants with animated videos depicting agents facing two action alternatives, which differed in the costs that the agents would have to incur, but ultimately led to the same rewards. The action costs were operationalized in terms of obstacles (blocks) that were blocking the agents' access to the rewards, and differed in volume (and therefore number of actions required to move them) as well as in whether they could be acted upon jointly (a single block) or individually (two separate blocks). In the beginning of each trial the protagonist agent had to decide which path to take towards the goal objects, whereas the second agent always followed the path chosen by the protagonist. The choice performed by the first agent was a crucial part of the experimental manipulation, as it allowed us to test infants' expectations about the agents' preferences, rather than infants' preferences only.

Experiment 10 (N = 24) was performed to test whether infants correctly infer instrumental costs based on the volume of the obstacles and the number of actions taken. The protagonist agent had to choose between two alternative routes, both requiring each agent to move their own obstacle. The obstacles were either large blocks that required each agent to perform three actions (Costly condition) or small blocks, which could be moved with a single action (Easy condition). According to the naïve utility calculus, infants should expect agents to incur minimal costs in pursuit of a goal, and therefore we predicted that choosing the more costly action alternative in Experiment 10 would violate infants' expectations.

Experiment 11 (N = 24) then addressed the critical question. In a nearly identical scenario to Experiment 10, agents faced two alternative routes, with identical costs and rewards as in Experiment 10, however with one crucial difference: the costly route of Experiment 11 involved a single large obstacle and thus allowed for the two agents to work cooperatively (Joint condition). The large obstacle in Joint condition had the combined volume of both large obstacles in Costly condition of Experiment 10 and required 3 actions on behalf of each agent. The alternative route was identical to the Easy condition of Experiment 10 and thus contained two smaller obstacles, which the agents could each move on their own with a single action (Individual condition). Considered from the standpoint of instrumental costs and rewards alone, the conditions of Experiment 10 and Experiment 11 are identical and should therefore yield the same results: infants should expect agents to take the route requiring fewer actions to reach the rewards. However, if infants have the expectation that agents should prefer cooperation over individual actions, Experiment 11 should show different results. Specifically, if infants in Experiment 11 expect the protagonist agent to choose cooperation despite the larger costs, it would indicate that infants infer a (non-observable) additional reward of acting together and that this reward outweighs the additional costs that the agents incur.

4.2 Experiment 10. Infants infer instrumental costs based on number of actions and object volume

4.2.1 Participants

Participants were twenty-four full-term 14-month-old infants (10 females, mean age = 14 months 11 days, range 14 m 9 d to 15 m 25 d) from Hungarian-speaking families, from larger Budapest area with no visual or hearing problems. 3 additional infants were excluded from the final sample: two due to fussiness and one for parental intervention. Parents signed an informed consent before taking part in the study, and all participants received a small toy as a gift for their participation. This research complied with relevant ethical regulations and was approved by the Hungarian Ethical Review Committee for Research in Psychology (EPKEB).

4.2.2 Procedure

All studies reported in this chapter have the same design structure, used the same procedure, apparatus and exclusion criteria.

Infants were tested in a quiet, dimly lit room, approximately 65 cm away from the computer monitor. They sat on their caregivers' laps. The caregivers wore darkened glasses, so that they could not see the stimuli. They was instructed not to interact with the child in any verbal or non-verbal manner. Furthermore, if the infant turned completely away from the stimulus for more than 5s, the caregiver was instructed to turn him back in the initial position facing the screen. This procedure ensured that infants could freely turn away when they were not interested in the display but could be reoriented for a next trial without interfering with the measurements.

The studies employed the violation of expectation looking time paradigm according to which infants tend to look longer at unexpected events (for a review see Aslin, 2007). We presented infants with test trials not preceded by familiarization. Our rationale was to avoid priming infants with different degrees of action efficiency and therefore register their spontaneous expectations in the experimental scenario. The order of the conditions counterbalancing was ABABABAB; which condition was displayed first was counterbalanced across participants. The last frame of each test movie remained still on the screen until the infant looked away for more than 2 consecutive seconds, or else looked at the screen for more than 30 cumulative seconds.

The experiment was ran on an Apple Mac Pro Quad Core 2.8 computer, controlled by PsyScope X (Cohen, MacWhinney, Flatt, & Provost, 1993). The stimuli appeared on a 24-inch TFT screen.

The experimenter monitored infants via the camera placed above the screen from a separate room. The recordings were further analysed offline.

4.2.3 Stimuli

The scene depicted an assembly of horizontally positioned blocks and barriers in the middle of the scene, with two agents (blue cylinder and yellow cone) in front of the barriers, and two red spherical objects - “apples” – behind them. Two groups of blocks on each side of the screen (left and right) constituted two alternative paths for the agents to reach the goal objects on the other side of the barriers. In Experiment 10 the action paths were Individual actions that differed in instrumental utility (Easy and Costly condition). Infants saw 8 movies, 4 Individual Easy and 4 Individual Costly condition trials.

On either right or left (counterbalanced) of the midline of the scene, there were two big blocks (Costly) and on the opposite side two smaller blocks divided by a barrier (Easy). Crucially, the two blocks in the Costly condition were 30% larger in volume than the sum of the two small blocks in the Easy condition. The videos depict the agents pushing either two smaller blocks or two big blocks individually. Once the obstacles have been cleared, they proceed towards the red spherical objects and ‘eat’ them.

Each trial started with the protagonist agent moving first, turning left and right, as if inspecting the options. After that, the protagonist started to move towards one of the two sides of the scene (choosing the means to achieve the goal, either Easy or Costly Action), while the second agent followed (fig. 17a).

In Easy trials each agent arrived in front of one of the small blocks and moved it away with one long push. Once the blocks were pushed away, the two agents moved around them, reached their goal object (apple), and ate it (fig. 17b). Onset and offset of the two agents' actions (pushing the block, and the approach of the goal object) were desynchronized by 1 second, so as to stress the independence of the two actions and to prevent that they would reach their goal object at the same time.

In Costly trials, both agents arrived in front of one of the big blocks and moved it away with 3 pushes. Once the block was pushed away, the two agents moved around it, reached their goal object (apple) and ate it. Crucially, in this condition both agents had to perform more actions to move the block away (which is understood by infants as a measure of effort - Scott & Baillargeon 2013), therefore making this condition instrumentally more costly.

In both conditions, the time to push the obstacles and to achieve the goal was the same. Moreover, in both conditions the agents reached their goal object at different times. This was made to ensure that infants could not attribute to the agent the goal of reaching the apples and eating them together. Side of Easy and Costly route options, and side of the protagonist relative to the follower (left/right) during the pushing actions, was counterbalanced across trials. This ensured that the order of agents' arrival at the goal object was also counterbalanced.

4.2.4 Results

Looking time was calculated based on off-line coding. Half of the sample (12 infants) was randomly selected and coded by the second coder. The inter-coder agreement was high, with correlational coefficient of 0.96.

Analysis of infants' average looking time, calculated across the repetitions of videos within each condition, revealed that infants looked significantly longer in the Costly than the Easy condition (ANOVA with condition as within-subjects factor: M_{costly}= 10.329, CI_{costly}= 8.72 – 11.9; M_{easy}= 8.072, CI_{easy}= 6.46 – 9.67 ; F(1,22)= 6.502, *p*=.018, η^2_p = 0.228). These results are also demonstrated at the individual level: 17 out of 24 infants looked in the predicted direction (p=.03, binomial test),

These results indicate that infants expected the protagonist agent to choose the less costly action alternative of achieving the same goal. They also demonstrate that infants are sensitive to the agents' instrumental utility and demonstrates infants' expectations about agents acting according to instrumental utility calculus.

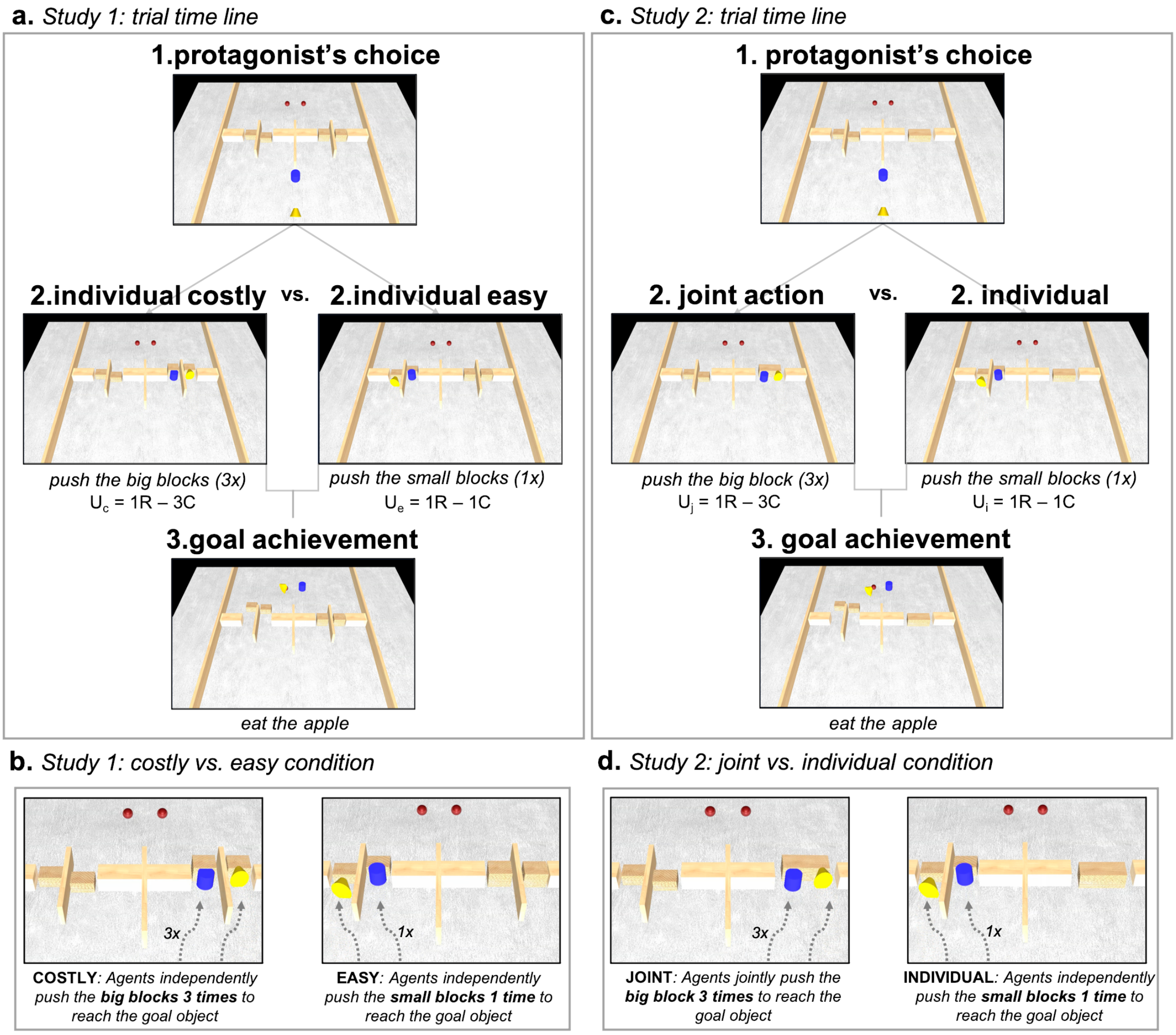

Figure 18: A. Trial timeline of Costly and Easy conditions of Experiment 10. *The protagonist agent (yellow) chooses which path to take (Costly/Easy) to reach the goal object (1). Agents push blocks away (2), reach the*

goal objects and eat them (3). Calculations of the observable utility (U), in terms of reward (R) and costs (C) computations of each action, are specified in the figure captions (2). ***B. Close up of Costly and Easy conditions of Experiment 10.*** *From the left, each agent in the Costly condition performs 3 pushes to remove the obstacles (blocks), 30% bigger in volume compared to the obstacles in the Easy condition. Each agent in the Easy condition performs 1 push to remove the small obstacles (blocks).* ***C. Trial timeline of Joint and Individual conditions of Experiment 11.*** *The protagonist agent chooses which path to take (Joint/Individual) to reach the goal object (1). After reaching the blocks (or single block in the Joint condition), agents push them away (2), reach the goal objects and eat them (3).* ***D. Close up of Joint and Individual conditions of Experiment 11.*** *From the left, each agent in the Joint condition performs a short push from the sides, after which both agents perform 2 pushes simultaneously to remove the single obstacle (block), 30% bigger in volume compared to the sum of the two obstacles in the Individual condition. Each agent in the Individual condition performs 1 push to remove the small obstacles (blocks).*

4.3 Experiment 11. Infants expect agents to cooperate despite higher costs

4.3.1 Participants

Participants were twenty-four full-term 14-month-old infants (11 females, mean age = 14 months 21 days, range 14 m 0 d to 15 m 10 d) from Hungarian-speaking families, from larger Budapest area with no visual or hearing problems. Six infants were excluded from the final sample: 4 due to fussiness and 2 due to equipment failure. Parents signed an informed consent before taking part in the study, and all participants received a small toy as a gift for their participation. This research complied with relevant ethical regulations and was approved by the Hungarian Ethical Review Committee for Research in Psychology (EPKEB).

Procedure

The procedure was identical to Experiment 10.

4.3.2 Simuli

Infants Each participant saw 8 test trials, half of them depicting a Joint Action, and half an Individual Parallel action. The Individual Parallel condition is identical to the Easy condition in Experiment 10 (one long push required to move the blocks). The Joint Action condition is equivalent in terms of the protagonist's relative utility to the Costly condition in Experiment 10.

On either right or left (counterbalanced) of the midline of the scene, there was one big block (Joint Action) and on the opposite side two smaller blocks divided by a barrier (Individual Parallel) (fig. 17c). Crucially, the single big block in the Joint Action condition was 30% larger in volume than the sum of the two small blocks in the Individual Parallel condition. The videos depict the agents pushing either two smaller blocks individually or one bigger block in coordination with their partner and, once the obstacles have been cleared, they proceed towards the red spherical objects and 'eat' them (fig 17d).

Individual Parallel trials were identical to Easy trials in Experiment 10.

In Joint trials, both agents arrived in front of the same big block: initially, each agent made a short push from the sides, after which they twice pushed the block simultaneously. Once the block was pushed away, the two agents moved around it, reached their goal object (apple), and ate it.

This condition is equivalent in terms of the protagonist's relative utility to the Costly condition in Experiment 10. All the movement properties of the agents in both conditions were identical to the two conditions of Experiment 10. The only crucial difference between the Costly condition and the Joint Action condition in Experiment 11 is that agents in the Joint Action condition acted on a single block together, therefore performed one individual and two coordinated actions.

4.3.3 Results

Looking time was calculated based on off-line coding. Half of the sample (12 infants) was randomly selected and coded by the second coder. The inter-coder agreement was high, with correlational coefficient of 0.95.

We measured whether infants' looking time differed between seeing the agents choosing to achieve the same goal together versus individually.

Analysis of infants' average looking time, comparing Joint and Individual conditions, revealed that infants looked significantly longer in the Individual than in the Joint condition (ANOVA with condition as within-subjects factor: $M_{individual} = 7.46$; CI = 6.50 – 8.42; $M_{joint}=5.97$, CI = 5.01 – 6.39; F(1,23)=5,8, $p = 0.024$, $\eta^2{}_p = 0.202$). At the individual level 17 out of 24 infants looked in the predicted direction (p=.03, binomial test), confirming the pattern. These results indicate that infants expected the protagonist agent to choose the Joint (and instrumentally more costly) over the Individual (and instrumentally easier) course of action.

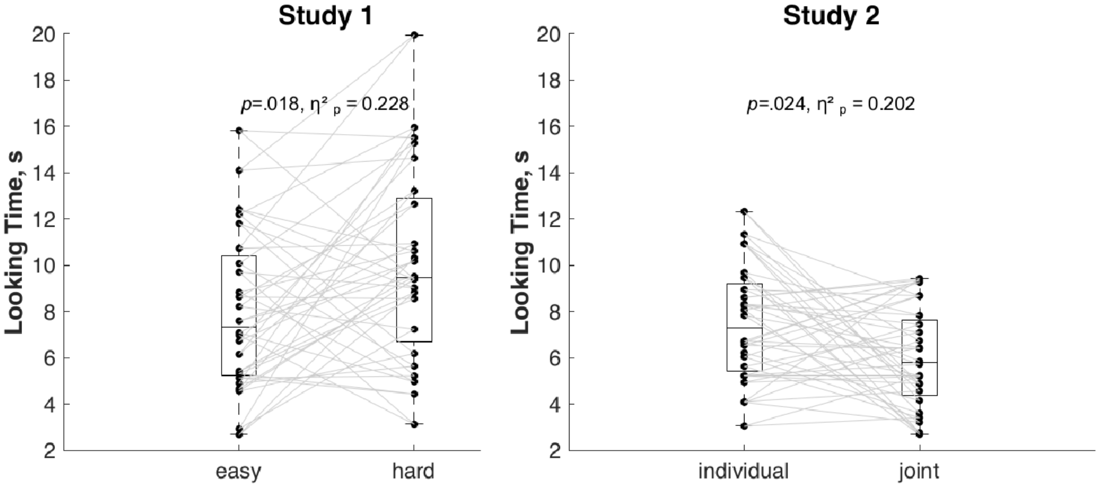

Figure 19: Boxplots of within-subjects average looking time in Experiment 10 and Experiment 11. Horizontal lines indicate medians and the bottom and top edges of the box indicate the 25th and 75th percentiles. Whiskers indicate the most extreme data points, not considered outliers. Black points connected across boxes with light grey lines indicate mean looking times from individual participants in the within-subjects' conditions. P values and partial eta squares indicate the significance level and the effect sizes of the mean looking time difference between conditions in the two studies. Statistical analyses are reported in the text.

4.4 Discussion

Our looking time results demonstrate that infants at 14 months of age expect agents to prefer to act together with a partner rather than achieve a goal individually. We also demonstrate that infants hold such expectations even though they are clearly sensitive to evidence that cooperation does not maximise an agent's individual utility. We argue that infants' expectation is based on the allocation of non-instrumental unobservable social rewards to cooperative actions. We suggest that infants' cognitive system does so by referring to an evolved built-in assumption that assigns an inherent reward value to acting together, which can tip the balance of the cost-benefit analysis in favour of cooperation as opposed to individual action.

Specifically, Experiment 10 tested infants' sensitivity to instrumental utility by comparing individual parallel actions differing in terms of the agents' utility. The results demonstrated that infants are capable of representing instrumental costs in the scenario we devised and expect agents to make instrumentally rational choices, in line with studies showing that infants expect agents to be utility maximisers (Liu, 2017). Crucially, when a different group of infants, in Experiment 11, saw an identical scenario in terms of instrumental costs and rewards, but one of the alternative routes allowed the agents to move the obstacles through cooperative action, infants expected the agents to work together. This was the case despite the fact that the cooperative action did not maximize the agents' (observable) instrumental utility, as more effort (3 actions) was exerted to achieve the same outcome. This provides evidence in support of the hypothesis that infants' expectations about agents acting together cannot be reduced to the sum of agents' individual utilities. Instead, it appears infants ascribe additional rewards to cooperative actions that go beyond observable costs and rewards of instrumental actions. Such unobservable rewards assigned to cooperative actions could constitute the computational justification for the humans' preference for cooperation. We speculate that such a mechanism of assigning additional reward value to cooperative activities beyond the instrumental utility could serve the function of motivating engagement in cooperative activities more broadly and from an early age.

Our findings support the hypothesis that infants are prone to see cooperation as valuable in itself and expect others to act together whenever there is an opportunity to do so. Since the desired goal in our studies *could* be achieved individually, the agent's decision to act together could not indicate a preference for mutualistic collaboration – a type of cooperative activity that individuals engage in when they cannot achieve a goal on their own, and which many other species are capable and willing to engage in (Tomasello et al, 2012). On the contrary, our scenario models a decision to engage in cooperation that is non utilitarian, as there is no observable necessity nor advantage to it. Arguably, such a scenario illustrates a paradigmatic case of purely social preference: agents choose to invest a higher observable energetic cost to engage in cooperation without any obvious prospect of immediate instrumental benefit. Even assuming that long term benefits are most likely utility-based constituents of human preference for cooperation, they are unlikely to directly guide infants' expectations about agents' choice to act together in a particular situation.

Next, we address possible alternative explanations for our pattern of results. One may argue that infants could generate predictions about agents' preferences for cooperation independently of the computation of its utility. They may simply rely, for example, on a heuristic strategy such as "agents will always choose cooperation whenever available". This would imply that, even though infants were sensitive to the instrumental utility in Experiment 10, in Experiment 11, when presented with a choice between individual vs. joint action alternatives, they could disregard the "instrumental" content of cooperative actions and processed only their "social" content. Consequently, infants would not need to ascribe additional rewards to cooperation itself in order to make sense of agents' decisions to act cooperatively. In other words, when faced with social interactions infants would bypass a detailed cost-benefit analysis of the instrumental actions' features, and expect agents to be simply driven by a prosocial attitude of preferring social interactions. However, in the particular scenario we designed, the only way infants could identify cooperative actions as such would be to process the specific properties of the instrumental actions. In fact, what distinguishes the cooperative from the individual parallel condition in our task is that both agents act on the same obstacle and coordinate their actions in space and time in order to remove it, as opposed to perform identical un-coordinated actions on different obstacles. As all other movement features and the relative positions of the agents in the two conditions were identical, we believe that infants' expectations for the agents' preference to act cooperatively can be best accounted for by assuming that they took into consideration the instrumental action features and interpreted them as cues of cooperation.

Chapter 5. Discussion

The research we presented in previous chapters was based on the proposal that humans possess an evolved sensitivity to cooperative goal-directed activities and ability to make specific inferences about the behavior of agents involved in such activities. We hypothesized that the properties of this adaptation are likely to be present early in the ontogeny; in infants who are yet not able to engage in such cooperative activities themselves.

As we demonstrated by exploring comparative literature and comparing humans with other species that are also social, there are uniquely human functionally related components that constitute "cooperative package" not found in any other species. We identified those components as:

1. active sharing (in particular of jointly acquired resources)
2. complex coordination and complementary role division in cooperative ventures
3. precise tracking of the amount of investment of different cooperative partners (“bookkeeping")
4. basic motivation to cooperate

We concluded that even though some rudimentary forms of all those components are present in other species, it is uniquely manifested in humans in a functionally interrelated manner to a degree that allows flexible and stable cooperation with kin as well as non-kin across the variety of the domain and on a scale unseen in any other species.

Additionally, we considered how all the key components together are critical for cooperation and contribute to the process of partner selection in stable social groups, which has likely constituted critical pressure in our ancestral environment for the selection of human-unique cooperative properties. We have argued that sensitivity and inferences about these key components should develop early in the ontogeny in order to prepare the ground for the ability to act cooperatively and eventually become a proficient cooperator. We have then explored whether infants can make some inferences that would follow from possessing an early sensitivity to the key elements of cooperation.

5.1 Infants' expectations about resource distribution

In Chapter 2 we asked whether 13-month-old infants make inferences about the distribution of jointly obtained resources between the cooperative partners, and contrasted it with resource distribution in a competitive setting. Indeed, infants differentiated between these two situations and expected agents to share their prey after seeing a "cooperative hunting" scenario (expressed by the cues such as joint efficiency in chasing, coordinating actions, and waiting for a partner in order to attack simultaneously; turn-taking interaction). Additionally, infants held the opposite expectation - that agents would not share - if in the chasing phase agents demonstrated cues of competition (hindering the rival and individual efficiency). We have then replicated this result using a different set of cues in the chasing scenario: we contrasted instrumental joint actions (moving obstacles together by coordination) with individual actions scenario (moving obstacles individually, while trying to hinder the competitor by blocking its way).

In these experiments infants faced a complex interpretation problem: how does one infer a cooperative context? Each of the presented cues could be non-cooperative if one does not understand the overarching context of joint goal pursuit, which involves mutual knowledge of the goal by the agents involved in the pursuit. Only knowing this an observer can interpret their actions as (jointly) efficient, as from the point of view of individual efficiency, agents' actions would often violate the efficiency principle.

Such joint analysis is more complex than simply attributing an individual goal to an individual agent: in this case, one must not only attribute but also distribute the goal between the two agents, as well as their mutual knowledge about the common goal. Every component is crucial: e.g. if an agent knows that the other agent has the same goal, but unaware it is their mutual goal but rather two individual goals, we arrive at a competitive scenario.

Another complexity infants had to face was the poverty of the stimuli. Despite the abstractness of the animated stimuli (all the agents in our stimuli lacked any anthropomorphic features such as eyes, faces, or limbs), infants were nevertheless able to interpret it as a complex social interaction and make inferences about how agents should behave in resource allocation problem they face in the test phase. This suggests that the minimal input criteria for performing such inferences were satisfied, which assumes a high level of abstraction for these representations. Where do they come from? Could they build such representations based on their own experience?

Infants’ ability to engage in cooperative actions increases around the age we tested (14 months) and such improvement in their own capacities might drive their understanding of third-person interactions. Henderson et al (2013) demonstrated that active experience helped 10-months old infants to understand collaborative goals better. Such evidence, however, comes from the paradigms with a direct link between the observed and performed actions: performing the same actions with the same objects as in the observation of the third-party. Not only to our knowledge there is no evidence that 13-months old do resource distribution as a function of invested work, but the first-person experience also could not have a direct correspondence with the observed events due to the abstract nature of the stimuli (not to mention the possibility of infants engaging in cooperative hunting seems unlikely).

Overall, the results of these sets of studies suggest that infants are sensitive to the investments in the joint venture, and expect that the returns it produces should be shared according to the social contract of cooperation. Fair sharing ensures stable cooperation by making cooperative ventures with the fair partners appealing.

However, we do not know what other types of interactions can produce the same expectations even without common investment. Possibly, for example, if some cues of kinship (e.g. mother-child interaction) are present, different expectations might be governing such relationships, and infants might expect resource sharing even with asymmetrical investment.

Additionally, in our studies, we did not address the question of how fine-grained infants' expectations about sharing are. We contrasted only two situations - either sharing equally or not sharing at all - while there is a range of sharing patterns, e.g. according to the amount of invested effort. Wang and Henderson (2018) demonstrated that 17-month-olds expect agents who contributed more to the common venture to take more of the rewards than the partner who contributed less. In light of this result, one possible experimental question is whether infants in our paradigm would have similar expectations of equity if we modify the procedure to demonstrate asymmetric investment of efforts. Alternatively, at 13 months of age infants are still too young to monitor individual contributions in a joint effort.

Partner choice theory predicts another factor regulating sharing in cooperative partners: namely, greater skills. That is, even if agents invested equal subjective effort, but one of them is more skilled, resulting in greater output, such agent is entitled to a larger share of the returns. Indeed, Cappelen et al (2007) found that adults, when judging rewards for actions others performed, found it fair to reward more effort (time spent on a task), but also to reward productivity (more results), thus confirming that competence entitles for greater rewards. Whether infants are sensitive to this factor remains to be explored.

Another interesting question is whether sharing expectation can be produced by cueing belonging to one group. Studies with school-aged children showed that they tend to share more with those who belong to their group (Fehr et al, 2008). In one of the studies we ran (sChapter 2, section 2.3), the agents were coordinated, moved together and looked the same (all could be cues of belonging to one group) but we did not find the expectation of sharing, suggesting group membership was not enough. However, our study did not include group membership contrast. One potential test could be presenting infants with two groups of agents, different looking and with different pattern of movements which has been shown to induce groupness (e.g. Powell & Spelke, 2013, Cirelli et al, 2018). Then in the test an agent would either share with an in-group or with an out-group. If there is a looking time difference between these two potential outcomes, it would suggest that infants expect agents to share with an in-group even in the absence of common investment. If this is the case, we could also test which factor - group membership or joint cooperative venture - would predict more resource sharing. In order to do that, we should familiarise infants with two groups; then the protagonist from one of the groups would pursue a joint cooperative goal (e.g. chasing an evader) with an outgroup member. Finally, in the test phase, it would either share with an outgroup - but also a cooperative partner - or with an ingroup member - but who did not contribute effort for obtaining the reward.

Another question that needs more exploring is what is the developmental trajectory of sharing. In our studies, 13-month-olds already expect agents to share resources obtained as a result of a common investment. As Hamman et al (2011) demonstrated, 3-year-olds tend to share with their partner if they both invested effort in a common venture (but not if they worked in parallel), but 2-year-olds do not respond to the jointness of the work and share the same whether they worked in parallel or jointly. Are 2-year-olds still sensitive to common effort and other processes interfere e.g. their tendency to share is interacting with their desire to possess the object themselves? Sloane et al (2012) demonstrated that at the age of 21 months infants expect two agents to be rewarded by a third-party if they worked on a common task, but not if one of them completed the task while another was playing (free-rider). Possibly, the difference in the results in these studies is a result of different methodologies: first-person behavioural study versus third-person observational. Infant comprehension and expectations might be ahead of their ability to act on them.

Another line of evidence comes from studies of first-hand sharing behaviour. 18-month-olds are reluctant to share with an adult if they are already in the possession of toys, which improves by 24 months of age (Brownell et al, 2013). This is different from the situation of windfall, however. When pairs of 18- and 24-month-olds were let into a room with appealing toys in the middle, they were able to share peacefully, and shared the toys equally in about half of the cases (Ulber et al, 2015; however, see Blake & Rand (2010) and Fehr et al (2008)). These results suggest that the developing concept of possession might be interfering with sharing.

Finally, there is a question of ecological validity. In our studies, we presented infants with distilled situations of cooperation, competition, and sharing. Needless to say, the real environment introduces a lot more noise, and the situations are not that clear-cut. Sometimes both types of interaction - cooperative and competitive - are mixed up, or spread over a long time. Following noisy, complicated real-life interactions, the inferences about sharing can be similarly complicated. We do not know what would be the value of a common investment.

5.2 Cooperation promotes agent individuation

In Chapter 3 we demonstrated that infants track the identity of agents involved in cooperative interactions easier than other agents.

We argued that the ability to recognize and track the identity of particular cooperative partners jointly pursuing a shared goal is part of the human-specific “cooperative package” of dedicated mechanisms that have been selected to support cooperative partner choice in human social groups. Our results provide supporting evidence for the hypothesis that this human specific adaptation that involves recognition of cooperative interactions of collaborating agents to pursue shared goals, which selectively induce activation of feature-based agent individuation and agent tracking is already present and can be demonstrated to function in young 13-month-old preverbal infants.

This is so in spite of the fact that at this early age infants are as yet severely limited in their ability to engage in active second-person cooperative activities with other agents and consequently lack relevant first-person motor experiences that could be informative about properties of cooperation and coordination in shared goal pursuit. We argue, therefore, that such active experience is not necessary and doesn’t form a precondition to acquiring the various domain-specific properties of cooperative interactions and collaborative activities to jointly achieve shared goals (as claimed by several alternative theories, see Henderson et al, 2013, Warneken, Gräfenhain, and Tomasello, 2012, Fawcett & Gredebäck, 2013, 2015). In fact, recent evidence using NIRS brain imaging suggests that already 9-month-old infants are able to attribute a shared goal to cooperative agents who optimize their coordinated joint actions to achieve their goal by minimizing the invested joint costs of their collaborative efforts (Begus et al., 2020).

Another open topic for discussion is the question of dispositions versus relationships. This suggestion - that it might be useful to track the identity of potential cooperators - or rivals - presupposes that infants attribute stable dispositional traits to agents, at least to a degree. It assumes that if agent A was friendly and cooperative to agent B, it might also be friendly and cooperative to me should we engage in interaction at some point. However, agent A's friendliness might be a property of its relationship with agent B and therefore be restricted to it.

It seems that even young infants use some form of trait attribution: in Hamlin et al (2007) and other studies following it, infants see a protagonist agent by being either helped to reach its goal by another agent (Helper) or being prevented from reaching its goal by the Hinderer.

After that, infants are presented with the two agents, and infants reach more often for the Helper agent (manual-choice paradigm). In order to hold such preference, infants should attribute a trait-like disposition to the agent and evaluate them based on this disposition, with the assumption that a given agent might behave similarly to other agents, including infants themselves. This is confirmed by the studies demonstrating that infants expect Helpers and Hinderers to act similarly toward third parties, with whom they were not involved previously (Geraci & Surian, 2011).

However, these results are contradicted by another line of evidence. Tatone and Csibra (2015) demonstrated that in the giving interactions infants did not expect givers to give to new recipients, hence the "giving" was not interpreted as a trait, but rather as a role and restricted to the particular relationship. Similarly, Mascaro and Csibra (2012) found that infants do not expect agent A to dominate over agent C (with whom it did not interact before), if agent A dominated over B, interpreting dominance as a property of a relationship, not personality. Finally, when adults are asked to give explanations for a certain behaviour, they retreat more readily to the previous history of interaction and context, rather than attributing personality traits (Gawronski, 2004; Malle, 2004).

The results of our studies can be interpreted as evidence of trait attribution - infants encoded chasing agents as "cooperators", which implicitly assumes that these agents would show cooperative tendencies as their stable dispositions. Once an agent is encoded as a cooperator, its relative importance is boosted and its features are being tracked better. It's retained more readily in memory. As long as agents in control conditions were not engaged in cooperative interaction, their identity is not retained as well, which is suggested by the results produced by comparing the groups.

However, our initial interpretation of these results in terms of investment tracking seems more parsimonious. Due to the nature of human cooperation, characterized by risky foraging and uneven distribution of returns over time (asynchronicity), as well as dependence on many cooperative partners, differing in their willingness to invest into cooperative ventures, as well as skills and talents. The necessity to engage in rounds of cooperation with different partners created pressure to identify and keep track of cooperative partners and their investments and likely shaped human bookkeeping system. Our results demonstrate that even at the age of 13 months infants track the identities of agents involved in cooperation more readily than agents not involved in such interactions, suggesting the early emerging preparedness

5.3 Infants expect other agents to cooperate

Finally, In Chapter 4 we addressed some questions regarding the developmental origins of human's motivation to engage in cooperation. Our finding suggests that infants expect other agents to prefer to achieve their goals cooperatively, rather than individually when they have such a choice. This result held even though the cooperative option was more instrumentally costly than the individual, and, as shown by Experiment 2, infants were sensitive to the differential costs of the actions when presented in the more versus less costly individual action alternatives.

Importantly, simply engaging in cooperation in itself presupposes a variety of non-trivial competencies that the human cognitive system must possess (Vesper et al., 2010). Cooperation through coordination could not be successful if humans did not rely on a range of dedicated cognitive processes, from mentalizing to representing conflicting perspectives (Moll et al., 2013), predicting and monitoring the partner (Loehr et al., 2013), representing the partner's actions and complementary role (Sebanz et al., 2003; Newman-Norlund et al., 2007). Arguably, when instrumental utility is kept constant, achieving a goal alone can be significantly less demanding than achieving it through coordination with a partner. What then would motivate an agent to choose the cooperative option that involves both more instrumental and cognitive costs? We hypothesise that a basic preference for cooperation would increase the likelihood of individuals to engage in cooperative activities may be selected on the basis of other grounds than instrumental benefit only.

In particular, we suggest that such readiness to engage in cooperative activities despite their immediate instrumental and cognitive costs has two main benefits: first, by frequently engaging in cooperation, individuals would increase the possibility to acquire skills and abilities necessary to become proficient cooperators and therefore exploit the large benefits that cooperative ventures offer. Secondly, it might provide an opportunity for individuals to engage in cooperative activities with a number of different partners and gather information about the quality of their cooperative skills and relevant dispositional properties (such as trustworthiness and commitment) in order to inform future partner choice. As a result, such preference would be an additional factor alongside instrumental utility and cost aversion that would be a part of the human cognitive system (Kool et al., 2010; Kurzban et al., 2013).

The present results pose fundamental questions for future research. First, the underlying cognitive processes that support infants' expectations about cooperative preferences remain to be explored. Our studies indicate that, when presented with evidence of instrumental actions' costs in a non-social scenario, infants are capable of identifying the action alternative that maximizes utility and expect other agents to choose this alternative. However, when comparing joint and individual actions, they seem to assign an additional value to the cooperative action alternative and combine it with the utility computation. We do not know, however, how such disparity is computed: whether it derives from infants downplaying the costs of coordinating with others or to assigning extra reward for engaging in cooperation that would compensate. Similarly, we do not know what are the limiting conditions of such a preference: e.g. would infants expect agents to prefer individual action, if the partner is unreliable or unhelpful, or cooperation requires much more physical effort?

Our studies also contribute to the interpretation of the nature of social vs. instrumental actions. One theoretical proposal recently made by Spelke (2016) suggests that young infants represent others as either individual agents performing instrumental goal-directed actions, or social beings performing social actions (such as affiliating with others). The integration of the agents' instrumental and social nature is proposed to take place only by the end of the first year of life. Our results demonstrate that at the age of 14 months infants already integrate information about both the instrumental and the social dimension of the action alternatives they are presented with. This is consistent with recent evidence by Begus et al. (2020) which showed that 9-months old infants are able to interpret the individually inefficient actions of two agents as goal-directed if they coordinated towards a common goal. It, therefore, remains to be further explored how infants develop and integrate core concepts of sociality and agency, that are so inevitably intertwined in human social life.

Relatedly, it is an open question of how infants represent and integrate the instrumental and social utility of actions. On the one hand, instrumental costs and benefits of actions may seem more directly and easily comparable, infants seem to easily map them onto the first-person experience such as felt degree of exerted effort, for example (although to specify the role and manner of how the experience actually contributes to these computations and judgments is far from being a trivial or clearly understood question, see Ullman et al., 2017). On the other hand, our results suggest that the process of quantification and comparison of rewards and costs of cooperative actions do not map in a straightforward way onto strictly physical principles. This poses the further challenge to identify what is the common currency that we use to compute, compare, or combine our estimated utility of instrumental actions with the utility we assign to cooperative social actions. One possibility is that we represent our estimated costs and benefits as subjective scale values that we associate with particular collaborative social or joint actions (values that we might generate through quite different computations and intuitive evaluations than what we rely on when estimating the expected costs and benefits of instrumental actions, say, in terms of expended versus gained amount of energy which, however, we also transform and represent in terms of associated scale values). This way we could then simply integrate the respective scale values associated with the social and cooperative activities within the utility calculation by comparing them with the entered values we have assigned to instrumental action costs and benefits. This would imply that infants can compute and compare different kinds of utilities associated with evaluated cooperative actions with estimated values of instrumental actions and arrive at preferential decisions using a system of the transformed common scale of comparison. Alternatively, the action context may determine the rules governing utility calculations. Once a specific type of action context is identified (e.g. “cooperation”), a dedicated utility scale is applied. By testing what degree or kind of individual instrumental costs infants would be ready to incur and still find preferable to engage in a cooperative action alternative to achieve the same individual benefit it would be possible to explore further questions about the nature of infants' representations of cooperative actions and their utility.

To sum up, in the infancy studies above we attempted to trace the ontogenetic origins and demonstrate the remarkably early presence and functional manifestations of some of the essential cognitive adaptations and specialized functional mechanisms that have been selected to serve cooperation in humans. These core mechanisms provide the basis for adult human groups' uniquely social propensity and basic preference to choose and maintain stable social cooperative relationships and engage in efficiently coordinated collaborative activities to jointly achieve their shared and highly adaptive common goals. We tested 13-month-old preverbal infants' understanding of cooperative (versus competitive or individual) goal-directed actions and interactions in a series of studies.

The tested infants who watched the interactive episodes from a third-person point of view were too young and not motorically mature enough yet to have had a previous motor experience of actively engaging in such complex mutual cooperative interactions with other agents: therefore, they lacked any first-person relevant experience that such interactions could have provided them with. The results we obtained converged to provide strong evidence to suggest that the 13-months old infants already possessed the various specialized perceptual mechanisms and relevant sensitivity that allowed them to recognize collaborative interactions and identify and individuate cooperative agents.

The recognition and encoding of such cooperation relevant agent-specific properties provide the informational basis to selectively choose the agent as a cooperative partner for future collaborative ventures (or rather to avoid him). Similarly to humans' basic social preference to engage in joint collaborative activities and coordinated social interactions to achieve shared goals, their adaptedness to encode the normative and investment-sensitive sharing of the common goal (e.g., sharing the prey) and distribution of the common benefits of their joint ventures are thought to be based on a suit of dedicated cognitive mechanisms that have been selected during hominid evolution to support cooperation.

Our series of results with infants discussed in the chapters above have provided further supporting evidence to show that most of these specialized adaptations are also already active at the early phases of human ontogeny in young preverbal infants. They arguably serve the adaptive function of sensitive observational learning mechanisms that allow infants to learn about the variety of different kinds of cooperative goals, variability of patterns of resource distribution as a function of differential or asymmetric investment by the partners, etc., that will make them more efficient cooperative partners in a wider variety of cooperative scenarios by the time they become mature and fully developed cooperative social agents.

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Appendix A. Cohesion violation and continuity of intentions

5.1 Introduction

5.1.1 Are attributed goals represented as properties of causal intentional agents or goal-directed intentional actions?

Young human infants already during their 1st year rely on a domain-specific core cognitive system specialized to interpret, represent, and reason about actions of causal intentional agents in terms of attributed goals (Gergely & Csibra, 2003, Carey 2009). Csibra and Gergely proposed that young infants have access to an action interpretation system that represents three components: a goal (an end state of an action), the physical context (representing environmental constraints on possible actions) and the most efficient means action available (given the physical context) to achieve the goal. Even three-months old infants are sensitive to action efficiency (Skerry, Carey, & Spelke, 2013) in relation to a goal outcome and the physical constraints in which the action is performed. By the age of 12 months they are able to make inferences about each of the three representational components based on information available about the other two (Gergely & Csibra, 2003, Csibra et al., 2003).

The teleological stance hypothesized by Csibra and Gergely is an interpretational system for representing the intentional goal-directed actions performed by causal agents acting under specific constraints of the given physical context. However, teleological reasoning about goal-directed actions is not based on or require explicit representations of agents, they only make reference to the actions, the goal outcome achieved, and the constrainimposed by the physical context. It is clear, however, that actions necessarily presuppose a casual agent performing them, so the relevance of agents as the causal source generating observed actions is unquestionable. At the same time this necessary background condition does not play an active computational or representational role in teleological action intertretation which attributes an outcome state as the goal of a specific action observed. The teleological inferential process solely relies on and exploits infants' capacity to compute the degree of efficiency of the observed action and compare it to the relative efficiency of alternative actions identified as a function of the given environmental constraints which specifies the set of possible actions that can bring about the same goal outcome in the given situation. This raises the theoretical issue whether the attributed goal is represented as the property of the observed intentional action or as the property of to the causal intentional agent performing it.

To address this question, Csibra and colleagues (Csibra et al., 1999) performed a set of experiments in which they examined whether cue-based identification of the causal agent is a precondition to attribute a goal to an observed action. In their experiment they presented to 9- and 12-month-old infants an ambiguous display of a moving object reaching a target through apparently efficient (vs non-efficient) pathways. The scene started with an object in movement entering the stage from the side. Having no perceptual evidence available about the starting origin of the on-going action of the moving object observed rendered the causal source inducing the visible action in the first place ambiguous to the observer. Even assuming knowledge by the observer of the necessary precondition of a causal agent who had generated the on-going and currently visible moving action in the first place, the identity of the causal agent who originated the action must have remained ambiguous to the observer. This is so because the object's motion could have been initiated equally by the moving entity itself in case it was a self-propelled causal agent who had generated its own intentional movement in the first place at a location outside of the screen that remained occluded from the observer, but it was equally possible that the visible moving object was, in fact, an inert inanimate object whose observable movement was induced by the physical impact exerted on it by a different causal agent's action outside of the screen, who launched it to fly into the the visible part of the screen.

The results showed that infants who were habituated to the moving object reaching the target efficiently attributed the goal to the observed action even though the observed movements of the ball provided no direct agency cues (e.g. self-propulsion or irregular path of movement). These results might indicate that infants can assign the goal to the action based on the efficient goal-directed pattern of the movements even when the identity of the causal agent remains unspecified.

In contrast, Saxe, Tenenbaum & Carey (2005) proposed that when infants observe goal-directed actions, they represent the goal as the intentional property of the individual agent who is the casual source of the action. They argued that infants infer and represent the agent both as a causal and an intentional entity at the same time, who provides the causal source of the action. These authors found that 10- and 12-month-old infants formed expectation about an invisible agent after watching the motion of an inanimate object. They observed repeatedly a beanbag being thrown from one side of the stage and landing at the other side. However, the beginning of the motion was occluded, so the beanbag was already in motion when it appeared flying in from the side. The looking time pattern indicated that infants were expecting an agent present at the side where the beanbag was coming from. Interestingly, the difference between the test conditions vanished when the beanbag was replaced with a self-moving puppet.

These results suggest that infants when seeing the motion of an inanimate inert object, inferred the presence of a hidden agent, who must have been the causal source whose intentional instrumental action on the object (launching it) led to its visible movement. In this view the success of goal attribution implies that infants must have assigned the goal to a particular causal agent: either to the moving object itself or to an inferred causal agent who had launched the object.

To sum up, Rational Action versus the Causal Agency account of goal attribution and representation offer different explanations about how infants represent the goal in relation to intentional actions on the one hand, and to the causal agent generating those actions, on the other. According to the Rational Actions account infants represent goals as a property of intentional actions without necessarily binding the action (and its attributed goal) as the intentional property mandatorily linked to the representation of the particular causal agent who generated the action. In this view actions can be assigned a goal as their intentional property even where they are represented with an unbound and referentially unspecified causal agent generating them. Conversely, the Causal Agency account assumes mandatory binding of an action goal as an intentional property of the particular causal agent who generates the goal-directed action. Since intentional causal agents are also physical entities, they must obey the principles of naive physics, such as solidity, continuity, and cohesion that preserves the identity of a causal agent (Spelke et al, 1992). Additionally, if a goal is interpreted as an intentional property bound to a particular causal agent, then the representation of the agent's goal must also be constrained by the physical principles that constrain the identity of the causal agent to which it is linked as its represented intentional property. Consequently, if a causal agent's physical identity and bodily integrity is disrupted (by violation of physical principles of solidity, continuity or cohesion) as a result it would cease to exist as a particular (and identical) agent. It follows then that its previously attributed goal represented as the referentially linked intentional property of the particular agent should also cease to exist (or loosing its 'host' causal agent to which it has been mandatorily bound as its intentional property, the goal would also 'loose its identity or existence'). The Causal Agency account also predicts that a goal-directed action represented as an intentional property of the animate causal agent who performs it, cannot be performed by an inanimate object like a box or a beanbag. In contrast, the Rational Actions account predicts that infants can interpret and attribute a goal as the intentional property of an action even if the action is performed by an inanimate object as long as the action satisfies the requirement of efficiency of goal-pursuit. Furthermore, it would also follow from the Rational Agency account of goal-directed actions, that represented goals of intentional actions should tolerate and potentially 'survive' violations of physical principles that disrupt the identity of the particular causal agent who generated their actions, as long as the goal-directed actions continue to be performed (by another 'host' agent with a different physical identity) and the actions continue to satisfy the expectation of efficiency of goal approach. Below we consider studies that attempt to empirically address and test these predictions.

5.1.2 Can goals be attributed to inanimate objects?

Kamewari et al (2005) suggested that for successful goal-attribution in infancy a familiar agent is required, such a human person. They tested this hypothesis in a series of experiments.

They habituated 6.5-month-olds to video events depicting a human person efficiently approaching a target object by making a detour around an obstacle that was blocking his way. The control group of infants saw similar events also involving a human agent following the same movement pathway to approach the target, but without the presence of an obstacle and so the very same detour action ceased to be the most efficient action alternative to approach the goal (in this condition the object in the middle was now placed on the side where it did not form an obstacle blocking the agent's straight path to the target object). During the test videos, infants saw two events both without an obstacle. In the Detour Path event the human followed the same trajectory as during the habituation event making a detour, but this time around a non-existent obstacle (fig. 3). In the Straight Path event condition, the person took the shortest path now available walking straight to the target object. Infants in the experimental group showed longer looking in the Detour Path test condition compared to the Straight Path test event, suggesting that they expected the human agent to change his path to a more efficient approach route now that the obstacle was absent. However, infants in the control group did not develop a different expectation about the human agent's action path in the absence of the obstacle.

In the second experiment, another group of infants saw the same pattern of actions to approach the target but this time these actions were performed by a humanoid robot rather than an actual human person. Contrary to their prediction, they found they replicated the same results, suggesting that infants were willing to attribute goals to unfamiliar non-human agents as well.

The authors suggested that feature resemblance with humans is enough to trigger goal-attribution and tested this hypothesis in a third experiment. Similar video events were presented in this condition as well with the only difference that now an inanimate object lacking any human features (a box) was performing the same patterns of actions to approach the target object. This time the difference between the efficient and non-efficient actions disappeared, apparently confirming their hypothesis.

However, an alternative explanation was proposed by Csibra (2008) to account for these results. In the experiment by Kamewari et al., the box was always following the same path, while in the previous experiment by Csibra et al. (1999) with inanimate agents, some aspect of the movements performed (e.g. the direction and relative height of the jumping actions) varied across the familiarization trials (as a function of the changing height of the obstacle they – efficiently -jumped over). It is possible that a repeatedly performed identical movement always following the same trajectory induced in infants an impression that the box was not an intentional agent, but a causal-mechanical devise that could not vary its behavior in a self-induced manner and could only move the same way following a specific and identical pathway.

In order to test this hypothesis, Csibra presented two groups of infants with stimuli similar to that used by Kamewari et al. (2005). In the first group (Single Route condition) infants saw video animations matching the experiment by Kamewari et al.'s (2005) study, while infants in the second group (Variable Route condition) saw very similar stimuli with one modification:

during the familiarization the box went around the obstacle either on its left or on its right side, introducing an element of apparently self-induced variability of approach (fig. 4).

The test phase was the same as in Kamewari et al.'s (2005) experiment: the obstacle was absent from the scene, and the box took either the same path (Detour path) or the shortest path (Straight path) toward the goal object. Similarly to the study of Kamewari et al. (2005) infants in the Single Route condition did not form an expectation about what path should the box take in the absence of the obstacle. However, infants in Variable Route condition looked significantly longer at the Detour path, suggesting that the slight variability of approach introduced during the familiarization phase was sufficient for infants to attribute intentional agency to the moving box object.

These results demonstrate, therefore, that infants agency attribution is not restricted to human and featurally familiar agents, and that variability of the target directed actions is a crucial cue for attributing goals. Infants infer and attribute goals to the actions of inanimate objects, as long as they satisfy the principle of efficiency of goal-approach and demonstrate other agency cues such as justifiable variability of goal-directed actions. These findings also provide further support for the teleological account of goals as intentional properties of actions.

5.1.3 Intentional agents should obey physical laws.. unless they pursue a goal?

The second line of evidence relevant for contrasting the Teleological Action account and Causal Agency account of goal representations come from exploring how infants react when observing physically impossible violations of object identity in the case of physical causal agents while they are performing actions of efficient goal-pursuit.

There are two separate core domains that need to be involved and integrated when representing the goal-directed actions of intentional agents. One is the domain of goal-directed intentional actions, and the other is the domain of physical objects and physical causal agents. As long as intentional actions are performed by material entities, they are both intentional and causal agents as well as physical bodily agents necessarily obeying physical principles of object identity (Spelke et al., 1992). The behaviour of physical objects follow principles of naïve physics that guide infant's reasoning about physical events (Spelke et al., 1994, Spelke, Phillips, & Woodward, 1995).

Agents similarly to any other solid material objects are expected to obey these principles of naïve physics. Infants reactions to the violations of these principles (e.g. with sustained attention and longer looking times) are considered markers of violation-of-expectation based on their reliance of these principles at an early age. But is it really the case that infants generalize these principles equally to all physical entities whose behavior or interactions they observe independently of whether they appear to be objects or agents? Saxe, Tenenbaum and Carey (2006) tested whether infants expect humans, as well as other agents, to follow the same physical principles of the core domain of naïve physics.

In their experiment Saxe et al., (2006) habituated 5-months-old infants to either a train or a hand moving across the scene coming out and stopping at its other end. During the test trials they placed a solid wall at the center of the stage that was blocking their pathway and occluded it with a non-trasparent screen placed in front of it. In half of the trials the wall was short and left a portion of the pathway free so that the moving objects could pass through all the way freely as before, thus not blocking the movements of either the inanimate train or the animate hand. In other half of the trials there was a different, longer wall placed in the middle that reached through the entire stage and so it physically blocked the previously free pathway through which both the train and the hand moved along to reach the other side. The test trials proceeded just as the habituation trials: an inamimate object (the train) or an animate agent (the hand) moved across the scene and stopped at the same point at the other end as before.

The results suggested that the infants looked significantly longer in during the trials with the long wall, regardless of whether it was the train or the hand that was moving across the scene. This indicated that infants are sensitive to the physical principle of solidity which implies that a solid physical object cannot pass through another solid object – in this case the wall blocking its path - and infants applied this expectation to human agents as well as to inanimate solid objects.

This result confirms the assumption that infants expect animate agents to obey the same physical principles as other inanimate physical objects. If goals are represented as intentional properties of the particular agents performing the goal-directed act, then under conditions where the behavior of a physical causal agent would violate the principles of naïve physics that maintain agent identity the goal previously attributed to the particular agent as its intentional property should also cease to exist or maintain its identity.

Here we provide two examples of studies whose result contradict this assumption.

Very informative from this point of view is an experiment performed by Southgate and colleagues (2008) demonstrating that biomechanically impossible actions do not interfer with infants' interpretation of action efficiency. Infants were familiarized to either a biomechanically possible series of efficient means actions performed by a hand to reach a goal-object or to a similar series of actions, but in this case one of the actions was an unnecessary and so inefficient sub-action that normally lead infants give up interpreting the series of actions as goal-directed. During the test phase, they were presented either with a biomechanically possible but less efficient action sequence (a hand moving obstacles out of its way to reach the goal-object) versus a biomechanically impossible but more efficient action sequence (a hand performing snake-like fluid movements efficiently getting through between the obstacles without having to remove them, as if it was a non-human rubber hand).The results showed that infants familiarized with the goal-directed biomechanically possible action series looked longer at the biomechanically equally possible but less efficient action series than at the biomechanically impossible but nevertheless more efficient goal-directed actions performed by the 'snake-hand'. This suggests that infants were not surprised to see the hand not obeying the biomechanical physical constraints that normally applies to the possible movements of human hands in case the 'impossible' hand was successfully approaching the goal and as long as it obeyed the principle of efficiency of teleological goal-approach.

Another recent series of studies by Téglás and Gergely (2014) appears to suggest that infants could maintain the goal-directed interpretation of an action, even when the causal agent performing the action went through a (pnysically impossible) transformation that violated its identity: it divided into two separater agents thereby violating the *principle of cohesion* of physical objects (according to which a moving solid object maintains its identity as long as the connectedness of its parts as well as the continuity of its boundaries are maintained, see Spelke et al., 1992).

The experiment depicted a large ball (the chaser) following a smaller ball (the chasee) in an efficient goal-directed manners (presenting movement cues of a heat-seeking goal approach, see Frankenhuis et al., 2013). At some point the chasee fled by going behind a fenced area through one of two entering gates. Whenever during familiarization the chaser pursued the chasee by following him and also going through one of the two entry gates to enter the enclosure, the chasee always managed to escape by leaving the fenced area through the other entry gate before getting caught. At one point, the chaser stopped in the middle before approaching the fenced area and performed an impossible action of self-division – it split into two smaller agents (which is a direct violation of the cohesion principle) and each of the resulting two new agents continued the goal-directed pursuit of the chasee by going after him to catch him behind the fenced area where it had just disappeared. This was achieved by one of the 'new' agent passing through one of the entry gates while the other 'new' agent went through at the same time the other entry gate leading into the enclosed area. Immediately after entering the fenced area they merged back into one agent again (by this also violating the cohesion principle) and then the thus 'reunited' chaser successfully caught the chasee. Infants looking times were measured from the time point when the chase was being caught (at which point the display stopped and remained stationary as long as the baby looked at the display or before it looked away for more than 2 sec). There were two conditions (see Fig 20.). In the "rational splitting" condition the fenced area had two lateral entry gates between which there was a solid wall (so for the two 'new' agents to divide and simultaneously enter through the two entry gates represented an efficient way to secure their goal of catching the chase. Therefore, splitting into two clearly appeared to be a ‘rational’ (if impossible) ‘means action’ that enabled the efficient and successful achievement of the goal.) In the “non-rational splitting” condition the middle wall was not present, so the chasee behind the fenced area would have had ample space and chance to escape the two laterally approaching ‘new’ agents (therefore, splitting into two was a relatively less efficient antion than it was in the “rational splitting” condition). Nevertheless, the chasee did not escape its two chasers in the latter condition either as those still managed to capture it.

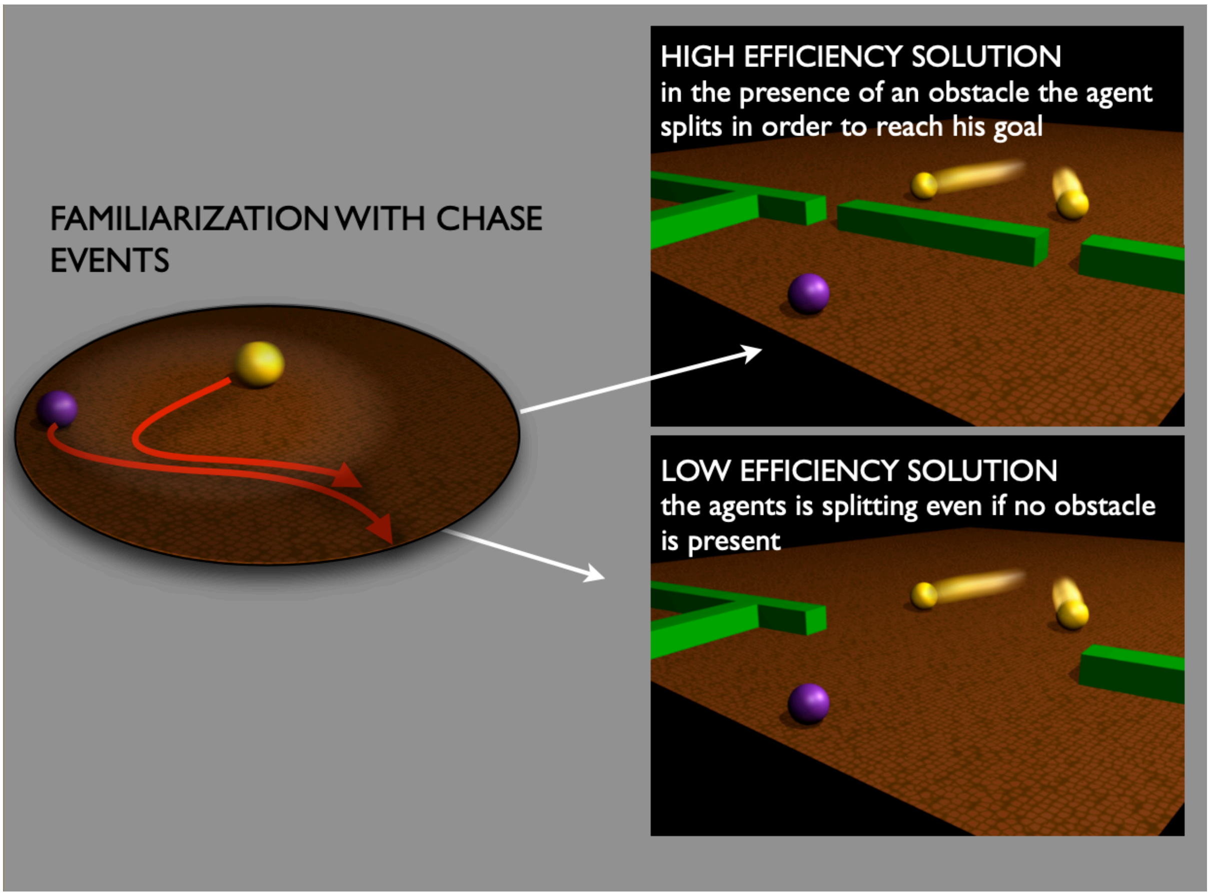

Figure 20. Two test conditions: “high efficiency” vs “low efficiency” split in Téglás & Gergely’s (2014) experiment. In the “high efficiency” condition there were two entrances to the enclosed area to where the chasee escaped, thus splitting into two maximized chance of realizing the goal by catching the chasee. In the “low efficiency” condition splitting into two also increased to some extent the probability to catch the chasee but this solution remained clearly inferior to the solution presented in the “high efficiency” condition, where the chasee had noway to escape after the chaser’s splitting into two.

The results showed that 10-months-old infants looked significantly longer in the (physically impossible) “non-rational splitting” condition as compared to the (physically equally impossible) “rational splitting” condition (even though in both conditions the chasee was eventually caught). This finding suggests that infants could maintain the goal-directed representation that continued to organize the subsequent flow of actions by the two ‘new’ agents who continued the efficient chase to realize the goal, even though the same goal had been originally attributed to the causal agent whose identity had been later violated by (the physically impossible) division into two new and separate agents.

5.1.4 How is the goal representation maintained?

In Chapter 2 we explored infants’ ability to differentiate and represent cooperative and competitive interactions, and how this induces in them different expectations about the agents’ future behaviour (in relation to resource sharing). In particular, in case of a cooperative interaction infants seemed to conceptualize the goal of the agents’ coordinated actions to catch the evading chase by representing it as their shared goal (otherwise they would not be able to interpret agents’ actions as efficient) and expected them to share the jointly achieved outcome of the cooperative chase. The opposite expectation was generated by infants who observed a competitive pattern of interaction: infants expected agents not to share the spoils, which suggests that they had interpreted the agents competitive chasing actions as being driven by their individual goals.

Based on these findings, we hypothesized that there can be at least two alternative explanations of how infants interpreted the events observed in the impossible splitting experiment of Téglás and Gergely (2014):

1) *The intention copying:* assumes that the two 'new' agents both continued to pursue the same individual goal of catching the chase: so the content of their intention remained identical to the intentional goal that drove the original actions of the 'old' source agent whose splitting created them. This possibility maintains the assumption that the link between the intentions and causal agent holding them cannot be detached. In accordance with this possibility the intention originally assigned to the 'old'agent remains continuously maintained and identical in content even after their 'host'agent had been split into two physically separate 'bew' agents who has apparently inherited and now carry (or 'host') the identical "copies" of the original agent's intention. In this case the two new agents' goal-directed actions will be driven by identical intentional goal states. An important consequence of this possibility is that in such a case their two identical individual goals to catch the same chase for themselves will create a conflict between them leading to *competitive interactions* as they simultaneously chase the same chase as their individual goals. That is, if the two 'new' intentional agents – who are now physically independent separate causal agents as well - are both pursuing their individual (but identical) goal and both attempt to to catch the same chase for themselves, the success of either one of them would exclude the success of the other. If identical individual goals are attributed to both agents, infants should not expect them to cooperatively share with the other agent their individual goal when it had been achieved. (In contrast, if the original goal of chasing the prey would become represented by the infants – following the splitting – as the now shared new goal content represented by both

of the ‘descendant’ new agents, infants would generate the opposite inference and expect the two agents to share the prey caught.)

2) *The intention distribution*. According to this possibility the goal of the original agent would not be simply copied with identical content as the respective goals of the two new agents, but rather would become converted and transformed into a joint mutual goal distributed between the two ‘descendants’ created by the original agents splitting into two In this case they would not inherit the same individual goal, but would be represented as sharing the original goal as their joint goal, as would be the case with two cooperative social partners of a joint venture. Such an interpretation may be imposed by the perceptual input being a ‘two chasers and one chasee action event’ which satisfies the input conditions that support a cooperative joint goal interpretation that involves the representation of two cooperative agents with a shared goal.

It appears possible to empirically contrast these two alternatives as they generate differential predictions about infants’ ensuing expectations as to what will happen to the goal object when it has been secured (concerning the expected likelihood of sharing versus not sharing of the prey caught). Therefore, building on our results from Studies 1-5 we designed a experiment to test the proposed theoretical possibilities.

5.1.5 The current studies

In order to address our experimental question, we took advantage of the paradigm developed in Experiment 1-5, which proved to be successful in demonstrating that infants are able to categorize and make differential inferences about joint vs individual goal pursuit in cooperative vs competitive contexts.

First, we aimed to replicate our original finding of the Cooperative Chase condition of Experiment 1, to show that infants indeed expect agents to share cooperatively gained resources. Experiment 12 was an exact replication of the Cooperative Chase condition of Experiment 1.

Next in Experiment 13, we presented the participants with the same chasing scenario used in our Cooperative Chase studies, but instead of three agents (two chaser and one chasee, the “prey”) initially there were only two agents presented: one chaser and one “prey”. Similar to the experiment of Téglás and Gergely (2014), the originally single chaser in the present experiment would split into two separate agents when approaching the fenced area where the chassee has escaped. From this point on the scenario would unfold in an identical manner as in Experiment 1, except for the absence of any cues of cooperative or competitive behaviour being produced by the two chasers. After the splitting event the two new agents immediately entered the enclosed area where the “prey” was then caught. During the following test event we presented the same two types of outcome - sharing versus no sharing - in order to test what type of goal (individual vs joint) had been assigned to the new agents by the infants after the splitting event.

5.2 Experiment 12: infants expect agents to share cooperatively gained resources (replication of Experiment 1)

5.2.1 Participants

Participants were twenty-four full-term 13-month-old infants (14 females, mean age = 13 months 17 days, range 13 m 01 d to 14 m 00 d) from Hungarian-speaking families. Eight additional infants were tested but excluded from the final sample: three due to fussiness, two for parental intervention, two for reaching maximum looking time.

Participants were recruited from the larger Budapest area. Parents signed an informed consent before taking part in the study, and all participants received a small toy as a gift for their participation. This research complied with relevant ethical regulations and was approved by the Hungarian Ethical Review Committee for Research in Psychology (EPKEB).

5.2.2 Procedure and Stimuli

Procedure and Stimuli was identical to Experiment 1 (Cooperative Chase condition)

5.2.3 Results

Looking time was calculated based on off-line coding of the video recordings. Half of the sample in each experimental group (24 infants in total) was randomly selected and coded by a second coder. The inter-coder agreement was high, with correlational coefficient of 97.8%

Looking time analysis (ANOVA with condition as within-subjects factor) showed that similar to the Cooperative Chase condition (Experiment 1) infants were surprised if the chaser agents did not share the prey as indicated by their longer looking times ($M_{NotSharing}$=10,2 s, SD=5.11) when compared to the test events that presented sharing the prey ($M_{Sharing}$=7,85 s, SD=6.7, F(1, 23)=5.25, p=.02; η^2p=.18). This result was also confirmed at the individual level, with 17 out of 24 babies showed looking time in the predicted direction (p=.03, binomial test).

5.3 Experiment 13: Cohesion violation and continuity of intentions

5.3.1 Participants

Participants were twenty-four full-term 13-month-old infants (11 females, mean age = 13 months 18 days, range 13 m 0 d to 13 m 29 d) from Hungarian-speaking families. Four additional infants were tested but excluded from the final sample due to fussiness.

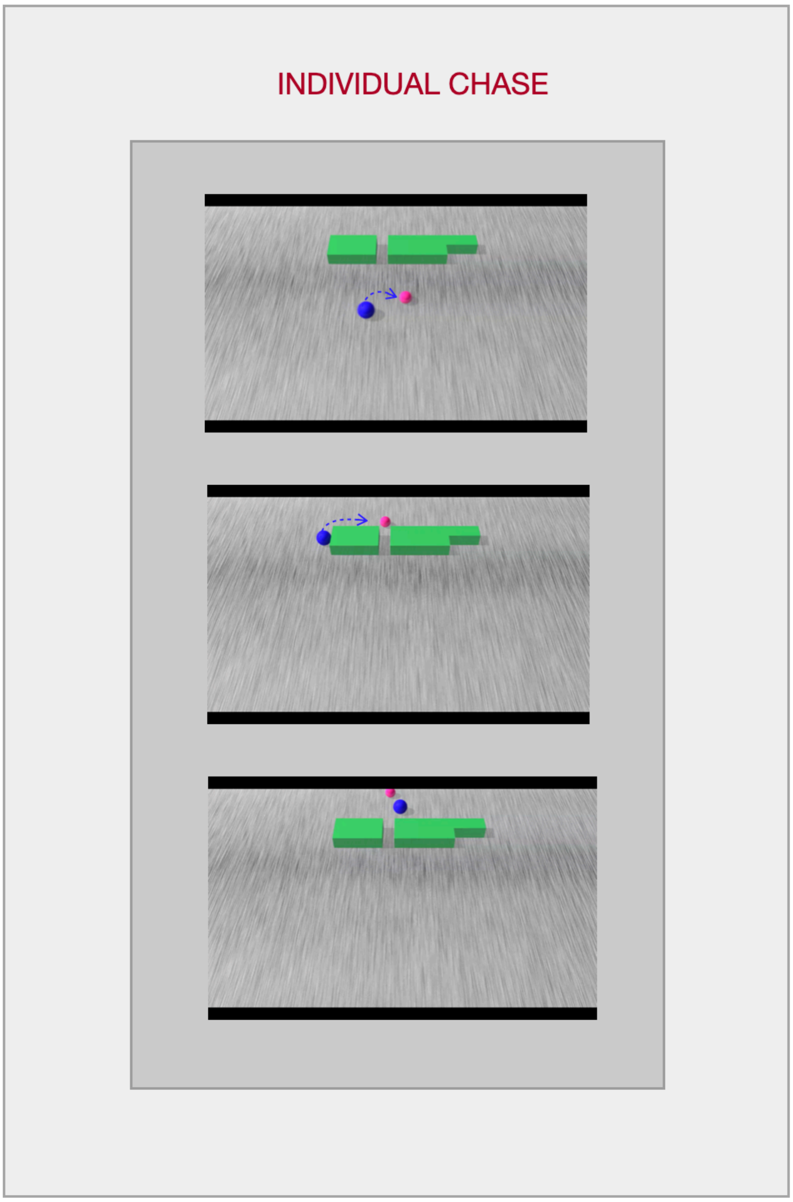

Figure 21. Familiarization trials in Experiment 13. Infants saw familiarizations events with one chasee following the evader.

5.3.2. Stimuli

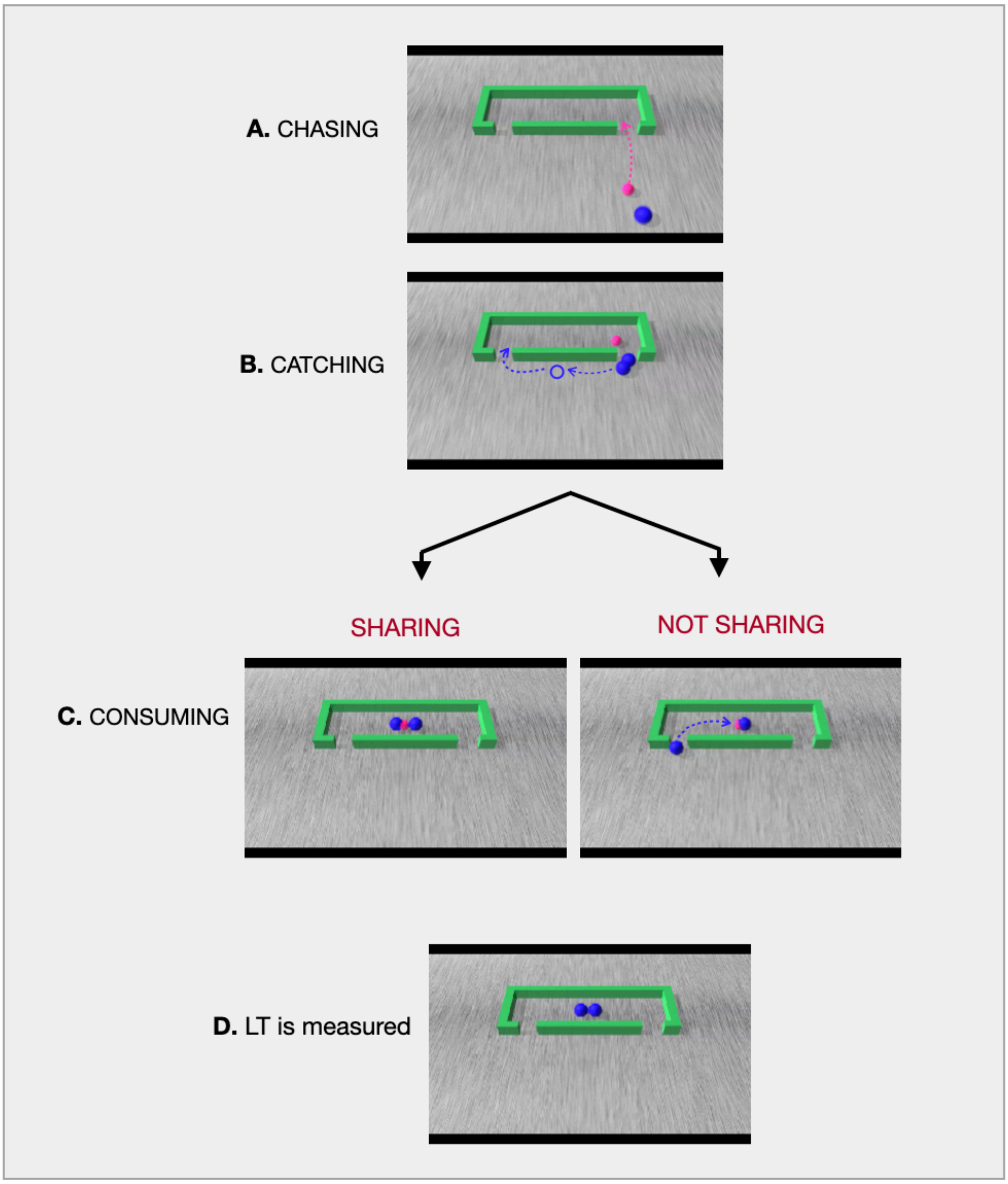

Figure 22. Test trials in Experiment 13. Trials started with one chaser following the chasee, but splitting into to new agents before the obstacle. After that each participants saw both outcomes: in Sharing outcome agents consumed the prey together and in Not Sharing outcome one of the agents consumed it alone.

Familiarization trials

The familiarization displays consisted of 3D animations depicting two spheric agents moving on a grey surface: one bigger blue ball, the chaser, and a smaller pink ball, the chasee.

The familiarization movies depicted these agents moving around the scene, from the bottom to the top of the screen, with the blue ball chasing the pink. In the middle of the scene there were two large objects with a narrow corridor in between them, forming an obstacle for the agents. After the initial phase of chasing (~ 8 s) the agents arrived at the objects. The smaller-sized chasee continued to move uninterruptedly passing through the small gap between the obstacles and stopped on the other side of the obstacles. The chasers tried to follow it through the gap but – being too large to fit in – could not get through but bumped back from the obstacle instead. After that the chaser went around the obstacle and attacked the evader from the side. The scene ended with the agents moving outside the screen, continuing the chase (4 seconds). Familiarization movies lasted for 20 seconds.

Similarly to our previous experiments, we incorporated chasing cues (Frankenhuis et al, 2012) of acceleration and attraction: the chaser pursued the chasee in a "heat-seeking" manner with sudden directional changes with speed acceleration towards the chasee.

Test trials

The scene depicted a large centrally located rectangular area delimited by solid barriers except for two openings ("entrances") on either side. Each trial started a chase event with the agents entering from outside to the scene (3 seconds). After reaching the fenced area the chasee entered through an entry hole to get to the other side of the fence. At this point, the chaser performed an impossible action: split into two agents (as in the Téglás and Gergely experiment), who followed the chasee from the two directions entering the fenced area through the two lateral entry gates and continued chasing to catch the prey as two separate goal-directed agents. The rest of the movie was identical to the studies in Chapter 1: one of the chasers caught the chasee first, after which it either waited for the second chaser to arrive as well at which point they consumed the prey together (4 seconds), or it ate the prey alone right after having caught it (4 seconds) (sharing vs no sharing outcome).

Each infant saw 2 test movies of each condition in ABAB order; the type of the first movie (sharing vs not sharing) was counterbalanced across the participants.

5.3.3 Results

The looking time after the final outcome was the dependent variable coded offline based on the video recordings of the participants.

Half of the participants (12 infants) was randomly selected and coded by a second coder. The inter-coder agreement was high, with correlational coefficient of 95%.

The data analysis (N=24) suggests that infants looking time pattern is similar to the Cooperative Chase in the Experiment 1 and Experiment 12: looking time was longer following the "non-sharing" outcome ($M_{NotSharing}$=12.12 s, SD= 8.15) than after the "sharing" outcome ($M_{Sharing}$=8.85 s, SD=6 s, F(1,23)= 8.32, p= 0.008, η^2p=.26) (fig. 22). At the individual level, 19 out of 24 babies showed looking pattern in the predicted direction (p=.003, binomial test)

This suggests that infants expected the chasers to share the rewards, which indicates that after the impossible split of the initial agent its goal has become represented as being distributed between the two new agents as their shared goal rather than being copied in an identical manner as the individual goal entertained by each of the two new agents who would therefore be in a competitive situation when chasing the single prey that they both wanted to catch for themselves.

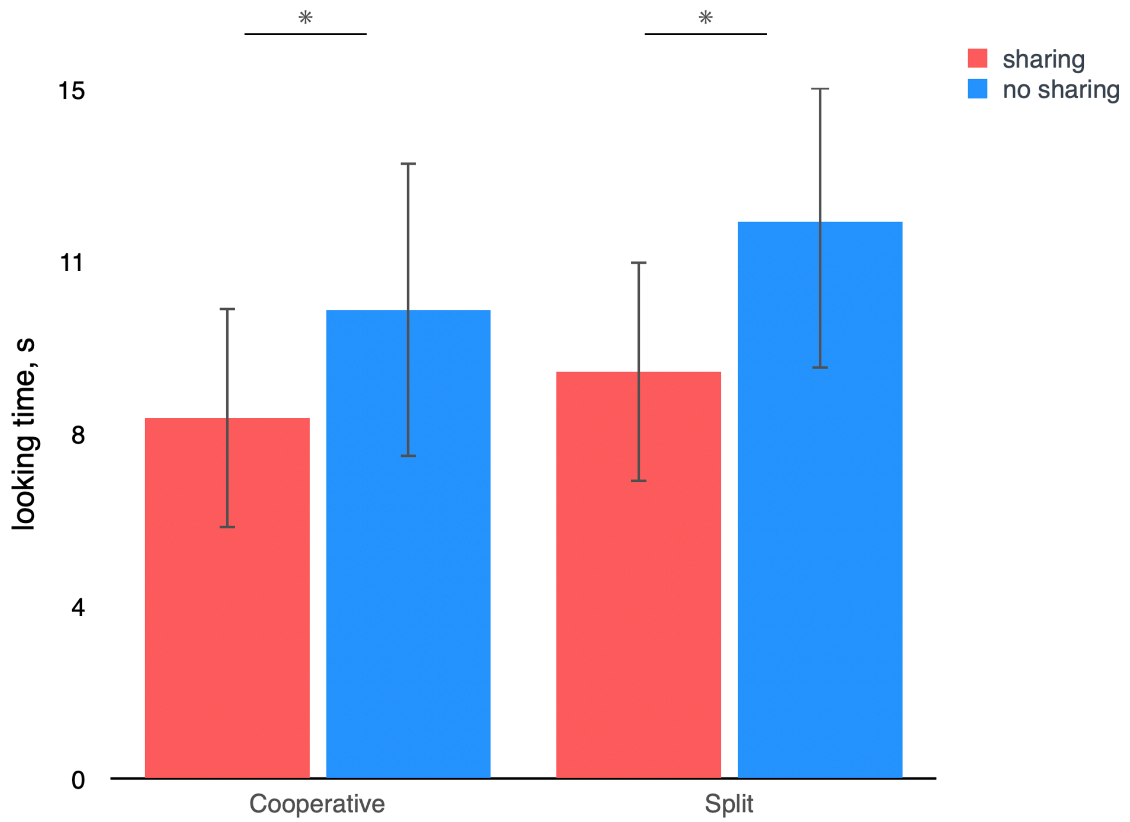

Figure 22. Looking times in case of sharing and not sharing outcomes in Experiments 12 and 13. Infants are surprised if the agents did not share after having seeing the cooperative chase (Experiment 12) and they showed the same differential pattern of looking times when following the splitting event the two new agents did not share the prey caught (Experiment 13, showing longer looking when the agents did not share the outcome).

Thus, our results suggest a possible explanation of how infants interpret cohesion violation. Not only do infants preserve the originally attributed goal if the cohesion violation is "justified" by the consequently more efficient pursuit of the goal, it seems that they "distribute" the represented goal between the two new agents, and expect them to act as cooperating individuals and share the prey they catch as a result.

Alternatively, some other factors may have played a role in determining infants' interpretation of the events. One possibility is that infants may have interpreted the two new agents as deriving from a "common origin": being the 'descendants' of ther initial agent who has been split into two. We can only speculate that the splitting of the original agent's identity into two producing two 'descendant' agents may have been interpreted as a cue indicating kinship relatedness and, as a result, it would induce similar expectations about sharing as we have demonstrated in the case of cooperative partners.

These results suggest that even though infants show early sensitivity to violations of naïve physics, their interpretation of the attributed intentions can go beyond this and result in differential expectations even in the case of physically "impossible" scenarios (as long as the subsequently observed actions of newly created (impossible) agents remain efficient and goal-directed). This may be the result of the fact that such input events involve two goal-directed 'new' agents following a single goal, which match and may activate complex representations of social cooperative interactive events involving cooperation and competition.

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