Journal of Experimental Child Psychology 226 (2023) 105564

Contents lists available at ScienceDirect

Journal of Experimental Child Psychology

journal homepage: www.elsevier.com/locate/jecp

Infants' representation of asymmetric social influence

Jesús Bas [a,b,*], Nuria Sebastian-Galles [b], Gergely Csibra [c,d], Olivier Mascaro [a]

[a] Integrative Neuroscience and Cognition Center, CNRS UMR 8002, Université Paris Descartes, 15006 Paris, France
[b] Center for Brain and Cognition (CBC), Universitat Pompeu Fabra, 08005 Barcelona, Spain
[c] Cognitive Development Center, Central European University, 1040 Vienna, Austria
[d] Department of Psychological Sciences, Birkbeck, University of London, London WC1E 7HX, UK

ARTICLE INFO

Article history:
Received 13 October 2020
Revised 7 September 2022

Keywords:
Social influence
Granger causality
Social relationships
Imitation
Model-learner relationship
Leader-follower relationship

ABSTRACT

In social groups, some individuals have more influence than others, for example, because they are learned from or because they coordinate collective actions. Identifying these influential individuals is crucial to learn about one's social environment. Here, we tested whether infants represent asymmetric social influence among individuals from observing the imitation of movements in the absence of any observable coercion or order. We defined social influence in terms of Granger causality; that is, if A influences B, then past behaviors of A contain information that predicts the behaviors and mental states of B above and beyond the information contained in the past behaviors and mental states of B alone. Infants (12-, 15-, and 18-month-olds) were familiarized with agents (imitators) influenced by the actions of another one (target). During the test, the infants observed either an imitator who was no longer influenced by the target (*incongruent* test) or the target who was not influenced by an imitator (*neutral* test). The participants looked significantly longer at the incongruent test than at the neutral test. This result shows that infants represent and generalize individuals' potential to influence others' actions and that they are sensitive to the asymmetric nature of social influence; upon learning that A influences B, they expect that the influence of A over B will remain stronger than the influence of B over A in a novel context. Because of the pervasiveness of social influence in many social interactions

* Corresponding author.
E-mail address: jesus.bas@upf.edu (J. Bas).

https://doi.org/10.1016/j.jecp.2022.105564
0022-0965/

and relationships, its representation during infancy is fundamental to understand and predict others' behaviors.

Introduction

To understand and engage in the social world, individuals need to properly represent the social relationships surrounding them. Many of these relationships are not symmetric. Instead, they are built on the greater capacity of some individuals to exert influence on others' mental states and behaviors (Burger, 2001; Forsyth, 2018; Izuma, 2017; VandenBos, 2007; Walker, 2015). Examples of this type of relationship could be model–learner and leader–follower relationships. In both cases, one of the interacting agents (the model or the leader) repeatedly influences others (the learners or the followers) in a nonrandom and significant manner (Boinski & Garber, 2000; Couzin et al., 2005; Glowacki & von Rueden, 2015; Pietraszewski, 2020; Smith et al., 2016, 2020; Van Vugt, 2006; Van Vugt et al., 2008). Recognizing agents' potential to influence others is crucial to represent social relationships and to predict and interpret many social behaviors. By testing whether infants represent asymmetric social influence within a group of interacting agents, the current study aimed to investigate the early developmental onset of this capacity.

In most social groups, some individuals have more influence than others in shaping their conspecifics' individual and collective behaviors. This greater capacity to influence others arises from various personal and social characteristics of the influential agents such as their expertise, prestige, control of relevant resources, authority, and popularity (Cartwright, 1965; Dahl, 2007; French & Raven, 1959; Gil-White & Henrich, 2001; Harris et al., 2018; Tooby & Cosmides, 1996). To this date, most studies of infants' representation of social influence have focused on the capacity of some individuals to impose their will on others. Studies of social dominance have shown that infants can identify who is likely to prevail when agents have conflicting goals. Infants can make such inferences on the basis of the size of the agents (Thomsen et al., 2011), their past interactions (Bas & Sebastian-Galles, 2021; Enright et al., 2017; Gazes et al., 2017; Mascaro & Csibra, 2012, 2014), the size of their supporting groups (Pun et al., 2016), or their relative spatial position (Meng et al., 2019). Infants also expect that agents are likely to obey authority figures (Margoni et al., 2018) who will intervene in unfair resource allocations (Stavans & Baillargeon, 2019). In short, these studies suggest that human infants are sensitive to forms of social influence in which dominant agents prevail in zero-sum conflicts or are being obeyed.

Crucially, individuals do not only influence each other in conflict situations or by giving explicit orders. As previously stated, there are many other reasons why some individuals are more influential than others. Although there are cues that help to identify influential agents, such as their posture, height, size, clothing, ways of speaking, and social group belonging (Brey & Shutts, 2015; Gülgöz & Gelman, 2017; Kinzler et al., 2011; Terrizzi et al., 2019), these cues can be misleading and are not always available. For instance, the most influential individuals in human groups are not certainly always the tallest or the largest agents; many other factors determine individuals' social influence such as their competence (Price & Van Vugt, 2014; Smith et al., 2016); thus, the size of humans is a feature that does not necessarily inform about their capacity to influence others. However, one can directly identify asymmetric social influence from the observation of behavioral dependence (Chang et al., 2017; Smith et al., 2016). If B's behavior is dependent on A's behavior and the reverse is not true, then A displays influence over B. More formally, social influence can be defined in terms of Granger causality; if the behavior of Agent A influences the behaviors or mental states of Agent B, then past behaviors of A contain information that predicts the behaviors and mental states of B above and beyond the information contained in the past behaviors and mental states of B alone. Defined in this manner, social influence is asymmetric; learning that A influences B does not necessarily imply that B influences A. In that respect, social influence differs from symmetric relations such as friendship; if A is friends with B, then B is friends with A.

Here, we focused on human infants' capacity to engage in such direct recognition of asymmetric social influence. That capacity might be indispensable for the comprehension of complex social relationships such as model–learner and leader–follower relationships. To this end, we induced the inference of social influence in infants by showing them a group of agents whose behavior was dependent on the actions of a particular individual; they consistently imitated the intransitive actions of the influencer. Later, we probed infants' expectations regarding the agents' capacity to influence each other in a different path-following scenario. We used the reproduction of movements and path following to convey agents' social influence because infants are sensitive to these cues from their first year of life (Powell & Spelke, 2013, 2018a, 2018b; Pulverman et al., 2008, 2013).

Two pieces of evidence suggest that preverbal infants might be able to detect asymmetric social influence from the observation of imitative behaviors. First, Powell and Spelke (2018a) tested whether infants infer the affiliative dispositions of agents on the basis of their roles in imitative interactions. The authors found that 4.5-month-old infants expected agents to approach and move in synchrony with other agents whose calls—sounds emitted by the agents—they had previously imitated but not the other way around. Second, the same authors in a different set of studies found that infants of this age preferentially attended to parties who imitated another agent's call over parties who responded nonimitatively. In contrast, when the same imitative and nonimitative responses were directed toward two different targets, infants did not show any preference to the imitated target (Powell & Spelke, 2018b). Altogether, these data suggest that infants treat agents who imitate others' calls from agents whose calls are imitated by others; in other words, infants differentiate between influential and influenced agents.

In our study, we focused on infants' capacity to detect asymmetric social influence when observing agents imitating others' movements. The aforementioned studies of Powell and Spelke also included movement imitation conditions, but the authors did not test infants' capacity to discriminate imitating agents from their models. One study provided evidence for such a capacity in children (Over & Carpenter, 2015, Experiment 2). In this study, 4- and 5-year-old participants saw a woman imitate the behaviors of another individual. Next, they were asked who was "the boss." By 5 years of age, children selected the woman who was imitated as the boss more often than predicted by chance. This result indicates that 5-year-old children could track who influenced the behaviors of whom. However, prior to 5 years of age, there is no evidence for young children's capacity to encode the directionality of social influence from observing one agent imitating another agent's movements. Our study addressed this issue by testing the early onset of this capacity in preverbal infants.

To test infants' representation of social influence, we designed a looking time study with 12-, 15-, and 18-month-old infants. We chose this age range based on previous studies of infants' capacity to infer one type of asymmetric social relation—social dominance—from agents' behaviors (Bas & Sebastián-Gallés, 2021; Mascaro and Csibra, 2012). During the familiarization phase, infants observed two agents (the imitators) consistently imitating the actions of a third agent (the target) and ignored the action performed by a fourth agent (the non-target). During the test phase, we measured infants' expectations in a novel situation where one agent chose a path to follow. In the "incongruent test," an imitator followed the path of the non-target agent instead of that of the target. In the "neutral test," the target followed the path of the non-target instead of that of an imitator. Note that both tests finished in the same way; one agent (the target or the imitator) chose the path of the non-target agent. If infants form a representation of agents' social influence, they should expect an imitator to be influenced by the target across different scenarios and, accordingly, would be surprised when the imitator does not follow the target agent during the incongruent test. In contrast, because of the asymmetric nature of social influence, infants should be less surprised when the target of imitation does not follow an imitator agent during the neutral test. Therefore, by contrasting the incongruent test with the neutral test, we tested whether infants represent asymmetric social influence; the behavior of the target has a stronger impact on imitators than the behavior of imitators has on the target. Contrasting an incongruent test with a neutral one, and not with a congruent test (in which the imitator would follow the target), had an additional advantage. Such contrast avoided the interpretations of the events in terms of affiliation. A congruent–incongruent contrast could be confused as a group membership test;

agents whose movements are alike may be expected to end up together (see, e.g., Powell & Spelke, 2013). With a neutral–incongruent contrast, the agents who act alike never end up together.

In addition to infants' looking time to the screen, we recorded infants' gaze behavior during the whole experiment. Because we had no a priori hypotheses of such data, we report them in the online supplementary material together with some exploratory analyses.

Method

Participants

A total of 48 infants were included in the analysis: 16 12-month-olds (M = 368 days, SD = 13), 16 15-month-olds (M = 473 days, SD = 10), and 16 18-month-olds (M = 564 days, SD = 8). The sample sizes of each subgroup were set to match those in previous comparable studies (Mascaro & Csibra, 2012; Thomsen et al., 2011). We performed sensitivity analyses using G*Power (Faul et al., 2007) in order to determine the size of effects that could be reliably detected with our sample sizes. These analyses revealed that a paired-samples t test with 48 participants would be sensitive to effects of Cohen's d = 0.41 with 80% power (alpha =.05, two-tailed). Moreover, a paired-samples t test with 16 participants would be sensitive to the effects of Cohen's d = 0.75 with 80% power (alpha =.05, two-tailed). Thus, our sample size was large enough to detect medium to large effects. An additional 74 infants were tested but excluded from the final analysis because of fussiness (i.e., when the participant became too distressed to make it possible to complete data collection; n = 23), parental interference (n = 4), experimental error (n = 9), looking at the screen for the maximum amount of time during both test trials (n = 1), or failing to watch the crucial choice event when one agent started to move toward one of two other agents (n = 37) (see Table S6 in online supplementary material). This last exclusion criterion, which was set a priori, resulted in an elevated rejection rate. In the supplementary material, we provide more information about this criterion and show that our results did not depend on it. The participants were recruited in the maternity rooms at private hospitals (Hospital Quirón and Clínica Sagrada Família in Barcelona, Spain). All participants were healthy full-term infants (born after > 37 weeks of gestation).

The study reported in this article was conducted according to the principles expressed in the Declaration of Helsinki and was approved by the local ethical committee. All parents signed an informed consent form for their infants to participate in this study.

Apparatus

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

Stimuli and design

The stimuli were computer-based animations involving four different "agents" represented by abstract geometric figures, each with a pair of eyes. At the start of all videos, the agents entered the screen. Two agents (the target and the non-target) positioned themselves along the screen central vertical axis, and two agents (the two imitators) positioned themselves along the screen central horizontal axis.

The familiarization phase consisted of four trials of the following sequence of events: The agents took positions on the screen and then the agents demonstrated their respective roles ("target," "non-target," and "imitators") (see Movie S1 in supplementary material and Fig. 1). To counterbalance the location of each agent across the familiarization, the agents changed their position on the screen in each trial. To do so, they gathered in the central area of the screen (1 s), they revolved 180° clockwise around the center following a semi-circular path (2 s), and they spread out by moving away from the center of the screen (1 s). After the agents took position, the target and the non-target performed different intransitive actions simultaneously (e.g., the target moved up and down while rotating, and the non-target moved horizontally from side to side) (4.5 s). After a delay of 1 s, the other two agents (the imitators) performed the same actions as the target (e.g., moved up and down while rotating) (4.5 s). Thus, at the end of the familiarization phase, the infants had observed the imitators imitate the actions of the target four times, whereas the non-target was never imitated. Across the trials, the actions of the agents varied using an ABBA pattern for the target and the imitators and a BAAB pattern for the non-target, where A and B refer to two different intransitive actions. Thus, during the familiarization phase, the target and the non-target performed the same two actions at the same two locations but at different times. We chose to use this procedure to show infants that all the agents could perform all the actions (including those performed by the non-target agent).

The pretest phase followed the familiarization phase without interruption. One imitator left the scene by moving out of the borders of the screen. The remaining imitator, the target, and the non-target positioned themselves at the top central part of the screen. In the incongruent movies, the imitator positioned itself above the target and the non-target at equidistance from them (5.5 s). Then, the

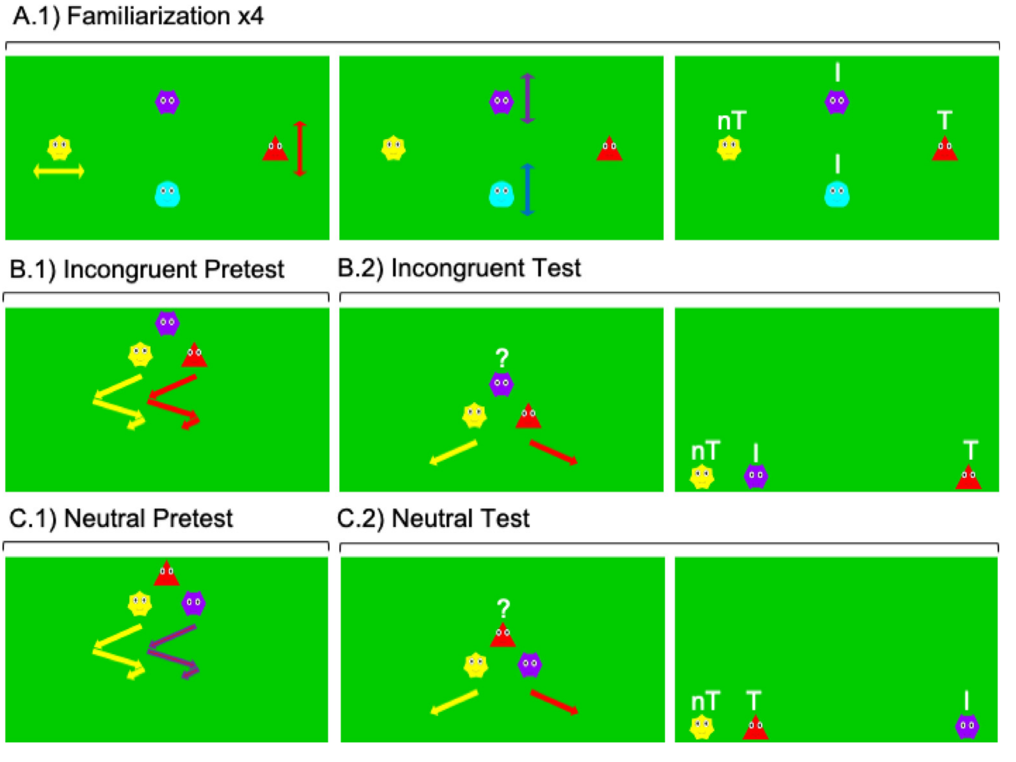

Fig. 1. Experimental stimuli. (A.1) During the familiarization phase, two agents—the target (T) and the non-target (nT)—performed two different actions. Next, two other agents—the imitators (I)—copied the action performed by the target. (B.1) During the incongruent pretest, an imitator followed the target and the non-target until the target and non-target took different paths. (B.2) The imitator then followed the path of the non-target (incongruent test). (C.1) During the neutral test, the target followed an imitator and the non-target until the imitator and non-target took different paths. (C.2) The target then followed the path of the non-target (neutral test).

target and the non-target slid down along parallel zigzag paths (1 s) before "calling" the imitator by emitting a sound while rocking gently from left to right (0.5 s). The imitator then moved toward the target and the non-target (1 s). This sequence (target and non-target moving downward before being followed by the imitator) was repeated four times as follows: The agents slid down diagonally twice in the left direction and twice in the right direction. At the end of this sequence (10 s), the agents ended up in the central area of the screen.

The test phase started when the target and the non-target moved in opposite directions (one toward the bottom left corner of the screen and the other toward the bottom right corner of the screen) (2 s). Then, the target and the non-target "called" the imitator by emitting a sound while rocking gently from left to right (0.5 s). The imitator then slid down along the central vertical axis (1 s), paused (0.5 s), and subsequently followed the path of the non-target (1.5 s). Once the imitator was close to the non-target, the video froze until the infants looked away from the screen for 1.5 s or after 30 s elapsed from the beginning of the move of the imitator.

The neutral movies (see Movie S2) were identical to the incongruent movies except that during the pretest and test phases it was the target who followed the other two agents as they moved down the screen. At the end of the neutral movies, the target followed the path of the non-target rather than the path of the imitator.

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

The participants were presented with one incongruent movie and one Neutral movie, each of them embedded in a block composed of a familiarization phase directly followed by the pretest phase and the test phase. For each participant, a different set of agents/actions was used in each block. The following factors were counterbalanced across participants: whether the block showing the neutral or incongruent test movies was presented first, whether a set of agents and actions was used in the incongruent or neutral movies, and the side of the screen occupied by the non-target agent in test movies (right or left side). For each set of agents, the geometric figures depicting the target agent and the imitator present during the test phase were counterbalanced across participants (red triangle vs purple hexagon for Set 1 and brown circle or orange pentagon for Set 2). The non-target and the remaining imitator agent were always the same geometric figure in their respective set (non-target: yellow octagonal star in Set 1 and blue square in Set 2; imitator absent during the test phase: blue rounded blob figure in Set 1 and pink trapezoid in Set 2). This procedure allowed us to use the exact same videos as neutral tests for half the participants and as incongruent tests for the other half (thereby ruling out interpretations of our results based on similarities between the agents' shapes). (More details about the stimuli combinations used for experimental counterbalances can be found in Table S9 of the supplementary material.).

The participants were presented with one incongruent movie and one neutral movie. The order of the movies presented was counterbalanced across participants. The test phase was presented without interruption after the familiarization and pretest phases. To be included in the data analysis, the infants needed to be looking at the screen at the crucial choice event at the beginning of the test phase. This event occurred when the centrally located agent (the imitator or the target) started to move toward the non-target. We set this criterion before running the experiment because we considered it crucial that infants witnessed the agent (the imitator or the target) choosing who to follow.

Coding and analysis

The video recordings were coded offline by analyzing frame by frame whether the infants looked at the screen or looked away during the test phase. The looking times were measured from the moment the imitator or the target started to move toward the non-target until the infant looked away for more than 1.5 s or after 30 s elapsed. Blinks were considered as looking away if they lasted for more than 0.2 s. Originally, the planned look-away criterion for stopping the test phase was set at 2 s to match comparable studies (Mascaro & Csibra, 2012; Thomsen et al., 2011). Because the experimenter mistakenly interrupted the test movie at 1.5 s in the first group of infants tested (18-month-olds), the look-away criterion was reduced to 1.5 s for the rest of the age groups. Thus, the protocol was readjusted in order to keep the protocol consistent among the three age groups tested.

The video coding was performed by a primary coder, who was unaware of the study purpose, and the first author. During coding, the primary coder and the first author could see only the infants' behavior but not the stimuli that infants were watching. A high intercoder agreement was achieved (intraclass correlation coefficient [ICC] =.992). We used the data from the primary coder to perform our analyses.

Shapiro–Wilk tests revealed that the looking times departed from normal distribution in both the neutral test event (W = 0.899, p =.001) and the incongruent test event (W = 0.858, p <.001). To better approximate normal distribution, we log-transformed the raw data before performing parametric statistics (Csibra et al., 2016). The means of the raw and log-transformed data can be found in Tables S1 and S2 of the supplementary material (the data for all individual participants are shown in Table S3). For ease of reading, the untransformed raw data are depicted in Fig. 2. For the effects of main interest, we also report nonparametric statistics. All the statistical tests were two-tailed.

Data availability

The looking times coded from video recordings of the current study are available in the supplementary material. In addition, the eye-tracker dataset used for the exploratory analyses described in the supplementary material file is available to all interested researchers upon request.

Results

The mean total looking times to screen during the test phase are depicted in Fig. 2. We performed a mixed-model analysis of variance (ANOVA) of total looking time at the screen with age (12, 15, or 18 months) and order of the test events (neutral outcome first vs incongruent outcome first) as between-participants factors and congruency (incongruent or neutral outcome) as a within-participants factor. The ANOVA yielded only a main effect of congruency, $F(1, 42)$ = 17.52, p <.001, η_p^2 =.294. Separate analyses of each age group revealed that older infants looked longer at the incongruent test events than at the neutral test events [15-month-olds: $t(15)$ = 3.30, p =.005, d = 1.20, Wilcoxon's z = 2.43, p =.015; 18-month-olds: $t(15)$ = 2.58, p =.021, d = 0.94, Wilcoxon's z = 2.48, p =.013). The effect of congruency did not reach significance among the 12-month-olds, $t(15)$ = 1.74, p =.103, d = 0.04, Wilcoxon's z = 1.50, p =.134.

Because of our a priori criteria, we excluded from our main analysis many infants who did not look at the screen when the agent located centrally followed the path of one agent or the other. Crucially,

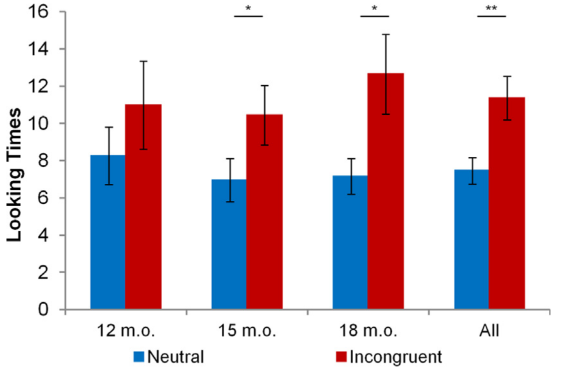

Fig. 2. Mean looking times at the screen (in seconds) as a function of age group and test events. Error bars represent standard errors. m.o., months old. *p <.05, **p <.01.

our results were not dependent on this specific exclusion criterion. When repeating our analyses while including the infants who missed the crucial event, we found the same pattern of significant results except that the effect of congruency was also significant for 12-month-olds (see supplementary material).

We also performed exploratory analyses on the eye-tracker data. Because these analyses did not yield any easily interpretable patterns of findings, they are reported in the supplementary material.

Discussion

Past studies have tested infants' representation of asymmetrical social relationships expressed through conflicts and orders, primarily focusing on social dominance (Bas & Sebastian-Galles, 2021; Enright et al., 2017; Gazes et al., 2017; Mascaro & Csibra, 2012, 2014; Pun et al., 2016, 2017; Thomsen et al., 2011; Thomas et al., 2018) and authority (Margoni et al., 2018; Stavans & Baillargeon, 2019). Here we focused on infants' capacity to represent agents' potential to influence others' behaviors in the absence of conflicts or explicit orders. We found that the infants successfully identified asymmetric social influence by tracking who imitated whom, although this result was weak for the 12-month-olds. Our results demonstrated that infants in the second year of life discriminate among individuals who influence others' behaviors (targets), individuals who do not influence others' behaviors (non-targets), and individuals whose behaviors are influenced by the others (imitators). Our participants expected that agents who were influenced by an individual during familiarization would continue to be influenced during the test phase by the same individual (the target). Moreover, upon learning that a target agent influenced imitators, infants expected the influence of the target over imitators to remain stronger than the influence of imitators over the target. Thus, our results suggest that infants formed an expectation of social influence based on a brief history of interacting agents even in the absence of identifiable conflicts, coercion, threat, orders, or tangible rewards.

During the past decade, the interest in infants' capacity to understand others' social interactions and social relationships has greatly increased (e.g., Bas & Sebastian-Galles, 2021; Enright et al., 2017; Mascaro & Csibra, 2012, 2014; Powell & Spelke, 2013; Rhodes et al., 2015; Stavans & Baillargeon, 2019; Thomsen, 2020). Most of this research has focused on infants' representation of agents' dominance and social affiliation, and it has revealed that infants assign distinct formal properties to different relations. Upon observing that an agent consistently prevails over another one, infants infer agents' social dominance (Bas & Sebastian-Galles, 2021; Enright et al., 2017; Mascaro & Csibra, 2012, 2014). When two agents' actions are systematically aligned, infants infer a positive social affiliation between those agents (Powell & Spelke, 2018a, 2018b; Pun et al., 2021). Our study moves the understanding of infants' social cognition forward; when two agents' actions are systematically aligned and one agent is always the one who performs the first action (and the other one copies), infants form a representation of the social influence of an agent over another.

Social learning and communication play a massive role in human cognition. As a result, humans need to be able to navigate a complex landscape of information sharing between individuals. In such an informationally promiscuous environment, having the capacity to track who influences whom (and thus who is the source and who is the recipient of information) is a crucial skill to identify the best sources of information, to predict and interpret others' behaviors, and to identify social relationships and structures. Tracking social influence might be particularly crucial for monitoring complex directed social relationships such as model–learner and leader–follower relationships.

Our results dovetail with data showing that 4.5-month-old infants treat agents who imitate others' calls differently from agents whose calls are imitated (Powell & Spelke, 2018a, 2018b). Here, we found that later in development infants can also track asymmetric social influence when observing agents' imitation of movements. The reproduction of movements plays an important role in social learning from an early age (Gergely et al., 2002; Király et al., 2013; Meltzoff, 1985, 2007; Over & Carpenter, 2013, 2015); for instance, infants' and children's imitation of motor behaviors is influenced by social factors such as group membership (Buttelman et al., 2013; van Schaik & Hunnius, 2016). Furthermore, infants extract social information from observing agents performing the same actions; they expect agents acting alike to end up together and to affiliate (Liberman et al., 2018; Powell & Spelke, 2018a). Thus, our results, combined with those of Powell and Spelke (2018a, 2018b), provide compelling evidence for infants' capacity to track social influence in a variety of imitative contexts. Importantly, all these studies showed agents performing and imitating actions whose specificities are not shaped by observable constraints. This type of imitation is particularly likely to convey social information because it allows observers to verify the hypothesis that an agent influences another one. Indeed, if an agent performs an action whose characteristics cannot be accounted for by observable constraints, the likelihood that a second agent would perform the exact same action by chance later on is very low.

Recognizing agents' potential to influence others' actions has several cognitive benefits. First, it can be used to identify influential individuals in a wide variety of contexts; for instance, it can be used to identify who others are learning from, following, or taking as a reference just by observing who acts first and who copies later. Second, it allows an observer to detect social influence even when the observer does not know about its source. In a nutshell, infants can determine who influences whom without forming complex representations about the factors underlying the influence such as agents' charisma, prestige, expertise, and popularity. This simplicity, when it comes to detecting influential agents, can be greatly useful during infancy. By identifying the source of social information relied on by the majority of group members, infants can determine from whom to learn, who is the leader, or who likes whom (Chudek et al., 2012; Gil-White & Henrich, 2001; Over & Carpenter, 2013, 2015; Powell & Spelke, 2018a).

Our study leaves several questions open. First, in our experiments, infants generalized their expectations of social influence from the familiarization phase to the test phase. Importantly, we do not claim that infants, upon observing that A influences B, infer that A will always influence B in all situations. In fact, in our study the test and familiarization phases differed only minimally. Whether infants would generalize agents' potential to influence others across widely different situations is an open question. It might be that infants expect some agents to have a greater general ability to influence others or represent social influence as specific to the pair of agents interacting and the context of the interaction. For instance, leaders are individuals who have a nonrandom differential influence on the behavior of their group no matter the context, whereas model–learner relationships tend to be context dependent; we learn from different individuals in different knowledge domains.

Second, our data do not tell whether infants' processing of social influence is supported by domain-general mechanisms (e.g., processes supporting representations of Granger causality across domains) or by specialized mechanisms dedicated to tracking influence between agents. Importantly, regardless of the scope of the mechanism supporting infants' expectations in our studies, it allows them to track social influence.

Third, research has revealed that infants, upon observing interactions between agents, infer social influence (our study) but also social dominance (Bas & Sebastian-Galles, 2021; Enright et al., 2017; Mascaro & Csibra, 2012, 2014), leadership (Stavans & Baillargeon, 2019), social partnership (Rhodes et al., 2015), or group membership (Powell & Spelke, 2013). Future research should investigate the extent to which these various representations differ from one another and interact. For instance, we have started to investigate whether dominant agents are expected to be more influential than subordinate agents in the absence of conflict or explicit orders.

Fourth, we tested infants' understanding of social influence expressed by similarity in behaviors using situations in which the actions or goals of a target are repeatedly reproduced by other agents (Cartwright et al., 2013; Clemson & Evans, 2012). However, real-world scenarios are much more complex; followers do not always merely reproduce what influential agents do. First, in a daily context, social influence is often more subtle; individuals influence not only others' actions but also their thoughts and beliefs, which are unobservable. Second, imitators and followers are not influenced by their targets indiscriminately; there are contexts in which influential agents play a crucial role and others in which they do not. Therefore, building on extensive research about how infants learn from and endorse others' knowledge, beliefs, and testimonies (e.g., Buttelmann, Zmyj, Daum, & Carpenter, 2013; Corriveau & Harris, 2009; Wood et al., 2013; Zmyj et al., 2010), future research should investigate whether infants represent the capacity of some individuals to influence others' mental states and actions in a broader set of contexts.

Data availability

The main data of the current study are available in the Supplementary Material.

Acknowledgments

We thank Cinta Bertomeu for working as a primary coder, Marc Colomer for his suggestions on improving the manuscript, and all families and infants who participated in the study. J. Bas was supported by: a pre-doctoral grant from the Spanish Ministerio de Economía y Competitividad BES-2013-063649 and a post-doctoral grant from Fyssen Foundation. N. Sebastian-Galles was supported by: LESOLA Project PID2021-123416NB-I00 financed by MCIN/ AEI / 10.13039/501100011033 / FEDER, UE; CECH Project, number 001-P-001682, cofunded by the European Regional Development Fund of the European Union (Programa Operatiu FEDER Catalunya 2014-2020) with the support of the Catalan Government; Research support official Id. P-5993 ICREA Acadèmia 2018 Award financed by ICREA; Research group support 2017 SGR 268 financed by AGAUR. G. Csibra was supported by: ERC Advanced Investigator Grant #742231 (PARTNERS). O. Mascaro was supported by: the French « Agence Nationale pour la Recherche » FoundTrust (ANR21-CE28-0017-01).

Author contributions

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

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jecp.2022.105564.

References

Bas, J., & Sebastian-Galles, N. (2021). Infants' representation of social hierarchies in absence of physical dominance. *PLoS One, 16*(2). https://doi.org/10.1371/journal.pone.0245450. Article e245450.

Boinski, S., & Garber, P. A. (2000). *On the move: How and why animals travel in groups*. University of Chicago Press.

Brey, E., & Shutts, K. (2015). Children use nonverbal cues to make inferences about social power. *Child Development, 86*(1), 276–286. https://doi.org/10.1111/cdev.12334.

Burger, J. M. (2001). Social influence. In N. J. Smelser & P. B. Baltes (Eds.), *International encyclopedia of the social and behavioral sciences* (pp. 14320–14325). Elsevier.

Buttelmann, D., Zmyj, N., Daum, M., & Carpenter, M. (2013). Selective imitation of in-group over out-group members in 14-month-old infants. *Child Development, 84*(2), 422–428. https://doi.org/10.1111/j.1467-8624.2012.01860.x.

Cartwright, D. (1965). Influence, leadership, control. In J. G. March (Ed.), *Handbook of organizations* (pp. 1–47). Rand McNally.

Cartwright, E., Gillet, J., & Van Vugt, M. (2013). Leadership by example in the weak-link game. *Economic Inquiry, 51*(4), 2028–2043. https://doi.org/10.1111/ecin.12003.

Chang, A., Livingstone, S. R., Bosnyak, D. J., & Trainor, L. J. (2017). Body sway reflects leadership in joint music performance. *Proceedings of the National Academy of Sciences of the United States of America, 114*(21), e4134–e4141. https://doi.org/10.1073/pnas.1617657114.

Chudek, M., Heller, S., Birch, S., & Henrich, J. (2012). Prestige-biased cultural learning: Bystander's differential attention to potential models influences children's learning. *Evolution and Human Behavior, 33*(1), 46–56. https://doi.org/10.1016/j.evolhumbehav.2011.05.005.

Clemson, T., & Evans, T. S. (2012). The emergence of leadership in social networks. *Physica A: Statistical Mechanics and its Applications*. https://doi.org/10.1016/j.physa.2011.11.011.

Corriveau, K. H., & Harris, P. L. (2009). Choosing your informant: Weighing familiarity and recent accuracy. *Developmental Science, 12*(3), 426–437. https://doi.org/10.1111/j.1467-7687.2008.00792.x.

Couzin, I. D., Krause, J., Franks, N. R., & Levin, S. A. (2005). Effective leadership and decision-making in animal groups on the move. *Nature, 433*(7025), 513–516. https://doi.org/10.1038/nature03236.

Csibra, G., Hernik, M., Mascaro, O., Tatone, D., & Lengyel, M. (2016). Statistical treatment of looking-time data. *Developmental Psychology, 52*(4), 521–536. https://doi.org/10.1037/dev0000083.

Dahl, R. A. (2007). The concept of power. *Behavioral Science, 2*(3), 201–215. https://doi.org/10.1002/bs.3830020303.

Enright, E. A., Gweon, H., & Sommerville, J. A. (2017). "To the victor go the spoils": Infants expect resources to align with dominance structures. *Cognition, 164*, 8–21. https://doi.org/10.1016/J.COGNITION.2017.03.008.
Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavior, and biomedical sciences. *Behavior Research Methods, 39*(2), 175–191. https://doi.org/10.3758/BF03193146.
Forsyth, D. R. (2018). *Group dynamics*. Cengage Learning.
French, J. R. P., Jr., & Raven, B. (1959). The bases of social power. In D. Cartwright (Ed.), *Studies in social power* (pp. 150–167). University of Michigan.
Gazes, R. P., Hampton, R. R., & Lourenco, S. F. (2017). Transitive inference of social dominance by human infants. *Developmental Science, 20*(2). https://doi.org/10.1111/desc.12367. Article e12367.
Gergely, G., Bekkering, H., & Király, I. (2002). Rational imitation in preverbal infants. *Nature, 415*(6873). https://doi.org/10.1038/415755a. Article 755.
Gil-White, F. J., & Henrich, J. (2001). The evolution of prestige. *Evolution and Human Behavior, 22*(2), 165–196. https://doi.org/10.1007/BF00992157.
Glowacki, L., & von Rueden, C. (2015). Leadership solves collective action problems in small-scale societies. *Philosophical Transactions of the Royal Society B: Biological Sciences, 370*(1683). https://doi.org/10.1098/rstb.2015.0010. Article 20150010.
Gülgöz, S., & Gelman, S. A. (2017). Who's the boss? Concepts of social power across development. *Child Development, 88*(3), 946–963. https://doi.org/10.1111/cdev.12643.
Harris, P. L., Koenig, M. A., Corriveau, K. H., & Jaswal, V. K. (2018). Cognitive foundations of learning from testimony. *Annual Review of Psychology, 69*(1), 251–273. https://doi.org/10.1146/annurev-psych-122216-011710.
Izuma, K. (2017). The neural bases of social influence on valuation and behavior. In J.-.-C. Dreher & L. Tremblay (Eds.), *Decision neuroscience: An integrative perspective* (pp. 199–209). Elsevier. https://doi.org/10.1016/B978-0-12-805308-9.00016-6.
Kinzler, K. D., Corriveau, K. H., & Harris, P. L. (2011). Children's selective trust in native-accented speakers. *Developmental Science, 14*(1), 106–111. https://doi.org/10.1111/j.1467-7687.2010.00965.x.
Király, I., Csibra, G., & Gergely, G. (2013). Beyond rational imitation: Learning arbitrary means actions from communicative demonstrations. *Journal of Experimental Child Psychology, 116*(2), 471–486. https://doi.org/10.1016/j.jecp.2012.12.003.
Liberman, Z., Kinzler, K. D., & Woodward, A. L. (2018). The early social significance of shared ritual actions. *Cognition, 171*, 42–51. https://doi.org/10.1016/j.cognition.2017.10.018.
Margoni, F., Baillargeon, R., & Surian, L. (2018). Infants distinguish between leaders and bullies. *Proceedings of the National Academy of Sciences of the United States of America, 115*(38), e8835–e8843. https://doi.org/10.1073/pnas.1801677115.
Mascaro, O., & Csibra, G. (2012). Representation of stable social dominance relations by human infants. *Proceedings of the National Academy of Sciences of the United States of America, 109*(18), 6862–6867. https://doi.org/10.1073/pnas.1113194109.
Mascaro, O., & Csibra, G. (2014). Human infants' learning of social structures: The case of social dominance hierarchies. *Psychological Science, 25*(1), 250–255. https://doi.org/10.1177/0956797613500509.
Meltzoff, A. N. (1985). Immediate and deferred imitation in fourteen- and twenty-four-month-old infants. *Child Development, 56*(1), 62–72. https://doi.org/10.2307/1130174.
Meltzoff, A. N. (2007). "Like me": A foundation for social cognition. *Developmental Science, 10*(1), 126–134. https://doi.org/10.1111/j.1467-7687.2007.00574.x.
Meng, X., Nakawake, Y., Nitta, H., Hashiya, K., & Moriguchi, Y. (2019). Space and rank: Infants expect agents in higher position to be socially dominant. *Proceedings of the Royal Society B: Biological Sciences, 286*(1912). https://doi.org/10.1098/rspb.2019.1674 20191674.
Over, H., & Carpenter, M. (2013). The social side of imitation. *Child Development Perspectives, 7*(1), 6–11. https://doi.org/10.1111/cdep.12006.
Over, H., & Carpenter, M. (2015). Children infer affiliative and status relations from watching others imitate. *Developmental Science, 18*(6), 917–925. https://doi.org/10.1111/desc.12275.
Pietraszewski, D. (2020). The evolution of leadership: Leadership and followership as a solution to the problem of creating and executing successful coordination and cooperation enterprises. *The Leadership Quarterly, 31*(2). https://doi.org/10.1016/j.leaqua.2019.05.006 101299.
Powell, L. J., & Spelke, E. S. (2013). Preverbal infants expect members of social groups to act alike. *Proceedings of the National Academy of Sciences of the United States of America, 110*(41), e3965–e3972. https://doi.org/10.1073/pnas.1304326110.
Powell, L. J., & Spelke, E. S. (2018a). Human infants' understanding of social imitation: Inferences of affiliation from third party observations. *Cognition, 170*, 31–48. https://doi.org/10.1016/j.cognition.2017.09.007.
Powell, L. J., & Spelke, E. S. (2018b). Third-party preferences for imitators in preverbal infants. *Open Mind, 2*(2), 61–71. https://doi.org/10.1162/opmi_a_00018.
Price, M. E., & Van Vugt, M. (2014). The evolution of leader–follower reciprocity: The theory of service-for-prestige. *Frontiers in Human Neuroscience, 8*. https://doi.org/10.3389/fnhum.2014.00363 363.
Pulverman, R., Golinkoff, R. M., Hirsh-Pasek, K., & Buresh, J. S. (2008). Infants discriminate manners and paths in non-linguistic dynamic events. *Cognition, 108*(3), 825–830. https://doi.org/10.1016/j.cognition.2008.04.009.
Pulverman, R., Song, L., Hirsh-Pasek, K., Pruden, S. M., & Golinkoff, R. M. (2013). Preverbal infants' attention to manner and path: Foundations for learning relational terms. *Child Development, 84*(1), 241–252. https://doi.org/10.1111/cdev.12030.
Pun, A., Birch, S. A. J., & Baron, A. S. (2016). Infants use relative numerical group size to infer social dominance. *Proceedings of the National Academy of Sciences of the United States of America, 113*(9), 2376–2381. https://doi.org/10.1073/pnas.1514879113.
Pun, A., Birch, S. A. J., & Baron, A. S. (2017). Foundations of reasoning about social dominance. *Child Development Perspectives, 11*(3), 155–160. https://doi.org/10.1111/cdep.12235.
Pun, A., Birch, S. A., & Baron, A. S. (2021). The power of allies: Infants' expectations of social obligations during intergroup conflict. *Cognition, 211*. https://doi.org/10.1016/j.cognition.2021.104630 104630.
Rhodes, M., Hetherington, C., Kimberly, B., & M. Wellman, H. (2015). Infants' use of social partnerships to predict behavior. *Developmental Science*. https://doi.org/10.1111/desc.12267.
Smith, J. E., Gavrilets, S., Mulder, M. B., Hooper, P. L., Mouden, C. E., Nettle, D., ... Smith, E. A. (2016). Leadership in mammalian societies: Emergence, distribution, power, and payoff. *Trends in Ecology and Evolution, 31*(1), 54–66. https://doi.org/10.1016/j.tree.2015.09.013.

Smith, J. E., Ortiz, C. A., Buhbe, M. T., & van Vugt, M. (2020). Obstacles and opportunities for female leadership in mammalian societies: A comparative perspective. *The Leadership Quarterly, 31*(2). https://doi.org/10.1016/j.leaqua.2018.09.005 101267.
Stavans, M., & Baillargeon, R. (2019). Infants expect leaders to right wrongs. *Proceedings of the National Academy of Sciences of the United States of America, 116*(33), 16292–16301. https://doi.org/10.1073/pnas.1820091116.
Terrizzi, B. F., Brey, E., Shutts, K., & Beier, J. S. (2019). Children's developing judgments about the physical manifestations of power. *Developmental Psychology, 55*(4), 793–808. https://doi.org/10.1037/dev0000657.
Thomas, A. J., Thomsen, L., Lukowski, A. F., Abramyan, M., & Sarnecka, B. W. (2018). Toddlers prefer those who win, but not when they win by force. *Nature Human Behaviour, 2*, 662–669. https://doi.org/10.1038/s41562-018-0415-3.
Thomsen, L. (2020). The developmental origins of social hierarchy: How infants and young children mentally represent and respond to power and status. *Current Opinion in Psychology, 33*, 201–208. https://doi.org/10.1016/J.COPSYC.2019.07.044.
Thomsen, L., Frankenhuis, W. E., Ingold-Smith, M., & Carey, S. (2011). Big and mighty: Preverbal infants mentally represent social dominance. *Science, 331*(6016), 477–480. https://doi.org/10.1126/science.1199198.
Tooby, J., & Cosmides, L. (1996). Friendship and the banker's paradox: Other pathways to the evolution of adaptations for altruism. In W. G. Runciman, J. M. Smith, & R. I. M. Dunbar (Eds.), *Evolution of social behaviour patterns in primates and man* (pp. 119–143). Oxford University Press.
van Schaik, J. E., & Hunnius, S. (2016). Little chameleons: The development of social mimicry during early childhood. *Journal of Experimental Child Psychology, 147*, 71–81. https://doi.org/10.1016/j.jecp.2016.03.003.
Van Vugt, M. (2006). Evolutionary origins of leadership and followership. *Personality and Social Psychology Review, 10*(4), 354–371. https://doi.org/10.1207/s15327957pspr1004_5.
Van Vugt, M., Hogan, R., & Kaiser, R. B. (2008). Leadership, followership, and evolution: Some lessons from the past. *American Psychologist, 63*(3), 182–196. https://doi.org/10.1037/0003-066X.63.3.182.
VandenBos, G. R. (2007). *APA dictionary of psychology*. Retrieved March 28, 2020, from https://dictionary.apa.org.
Walker, L. S. (2015). Social influence. In G. Ritzer (Ed.), *The Blackwell encyclopedia of sociology*. https://doi.org/10.1002/9781405165518.wbeoss154.pub2.
Wood, L. A., Kendal, R. L., & Flynn, E. G. (2013). Whom do children copy? Model-based biases in social learning. *Developmental Review, 33*(4), 341–356. https://doi.org/10.1016/J.DR.2013.08.002.
Zmyj, N., Buttelmann, D., Carpenter, M., & Daum, M. M. (2010). The reliability of a model influences 14-month-olds' imitation. *Journal of Experimental Child Psychology, 106*(4), 208–220. https://doi.org/10.1016/j.jecp.2010.03.002.