Universal quantification without language? Ten-month-old infants represent the universality of visually presented properties.

Universal quantification–the logical operations lexicalized with "all", "every", and "each"–supports the universal (i.e., without exception) application of a predicate to the things that fall under a concept. By means of logical quantification, the human mind can represent universality over an infinite number of entities (e.g., "EVERY natural number is divisible by 1"). However, inferring such a representation requires sophisticated deductive abilities. In contrast, in everyday life, we can also easily notice universality in our immediate visual experiences (e.g., "look, ALL the apples in front of us are green!"). Our ability to detect universality based on observable data paves the way for studying forms of universal quantification beyond language (e.g., at the interface with vision) and their cognitive development. With six experiments, we provide initial evidence that preverbal infants represent the universality of visually-presented actions in much the same way as adults.

The distinction between individual-implicating (first-order) and group-implicating (second-order) forms of universal quantification is fundamental to logic and language (Knowlton et al., 2021). When prompted with quantified sentences (e.g., is each dot blue? Are all the dots blue?), speakers verify the universality of visually-presented properties by recruiting a-linguistic cognitive systems dedicated either to the tracking of individuals (i.e., the object-file system, Scholl 2001) or of groups (i.e., the ensemble systems; Alvarez, 2011) in the environment. These core systems are already in place in the first year of life. Can human infants deploy them to detect universality without using linguistic quantifiers?

Here we ask whether mastery of words like "all" and "each" is required to think about universality and to detect it in visual scenes, just as it has been argued that children need the words “one” "two", "three", "four", and "five" to represent cardinalities of exactly 5 items (Carey, 2009; Frank et al. 2012). In contrast to this strong Whorfian view, we offer initial evidence that 10-month-old infants have access to preverbal forms of universal quantification long before acquiring quantifier words, in line with the proposal that precursors of logical capacities may be in place in infancy (Cesana-Arlotti et al. 2018).

In an initial series of experiments, adult participants watched simple animations, with no linguistic descriptions, involving agents performing goal-directed actions (e.g., scenes of three/five/eleven chevrons, EACH chasing a ball alone, or of three/five/eleven chevrons, ALL chasing one ball together; see Fig.1 for one example of our procedure). In the EACH situations, adults were less likely to detect universality when the number of agents exceeded working memory limits (i.e., > 4 agents), indicating that universality was represented across multiple discrete events (e.g., $chevron_1$_chasing_$ball_1$; $chevron_2$_chasing_$ball_2$; …). In ALL situations, adults were equally likely to notice the universality no matter how many agents were present, in line with the computing of universality based on a single collective representation (e.g., an ensemble). The interaction between the number of agents and the distribution of goals indicates two representations of universality (group- and individual-universality).

Next, we asked whether 10-month-olds notice the universality of goal-directed actions similarly to adults in five visual-habituation experiments (See Fig.2 for a description of our procedure). In Experiments 2 and 3 (n = 24 each), infants who were habituated to ALL videos with three chasers successfully dishabituated to EACH videos with three chasers ($p = 0.008$), and vice versa ($p = 0.01$; Fig.1). This result shows that infants encoded different representations of our ALL and EACH movies. However, it remains unclear how such difference was encoded: along some low-level perceptual dimension (e.g., variability in the orientation of the chevrons' tips), or else in terms of the contrast between group- and individual-universality?

In three ongoing studies, we habituate infants to 5-agents "all" videos (Experiment 4, n = 27/30), 5-agents "each" videos (Experiment 5, n = 15/30), or 3-agents "each" videos (Experiment 6, n = 0/30). In all three cases, we test for dishabituation to "broken-chasing"

movies in which the chevrons are not pointing toward the target they chase but toward empty locations. Thus, the change in the variability of the orientations of their tips is equated across the three experiments (see Fig.2), and, thus, equally detectable. In contrast, preverbal representations of group- and individual-universality predict that infants, like adults, will fail to form a robust representation of 5-agent EACH chasing (as 5 is above their working memory limit for individual items; Feigenson, 2004), but will succeed in the 5-agent ALL and 3-agent EACH chasing conditions. Preliminary analyses initially confirm our predictions: in Experiment 4, infants dishabituate to broken chasing ($p = 0.02$), while in Experiment 5, they do not. These results point to a preverbal precursor of linguistic quantification in infants' representations of the universality of visually-presented actions. This supports the idea that language acquisition is not a prerequisite for basic forms of universal quantification.

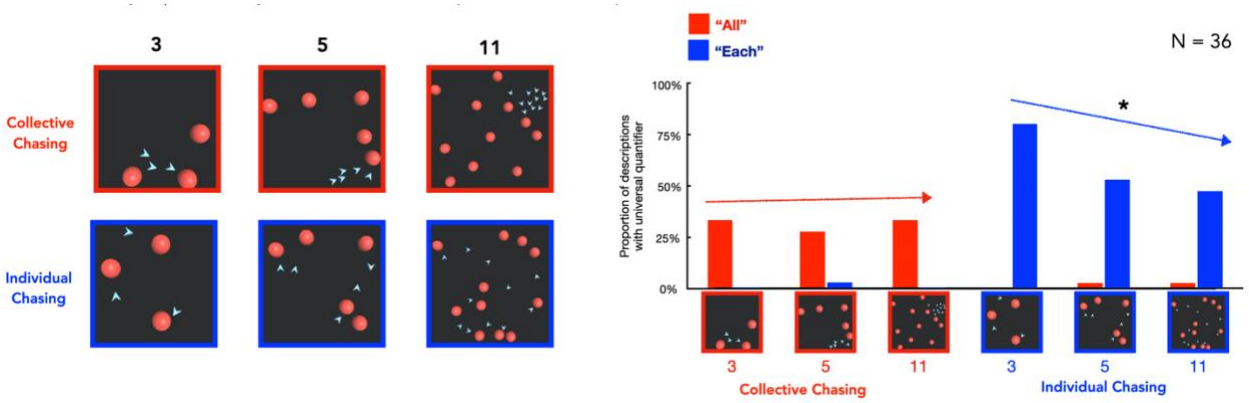

Fig. 1. Design and results of Experiments 1 (adults). In a MOT design, participants were asked to describe our movies. Across six conditions, we varied the distribution of the target and the number of agents. Each of the participants was presented with each of the six movies, exactly one time. After each movie, the participants were asked to describe it. At no time during the experiment were participants told to use quantifiers to describe the movies. We measured the proportion of trials where quantifiers were used to apply CHASING.

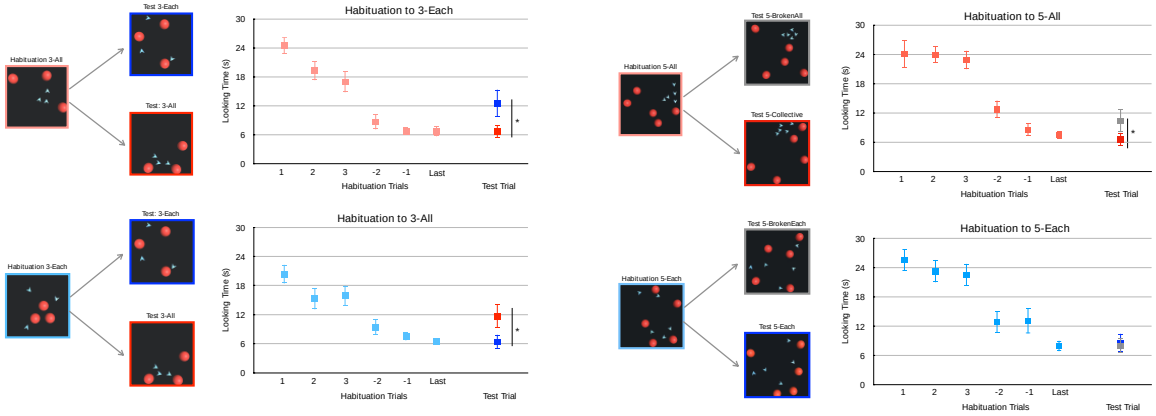

Fig. 2. Design and results of Experiments 2-5 (infants). In our procedure, an infant saw a sequence of videos of the same type (e.g., 3 agents, each chasing a ball alone), and, each time, we recorded how long the baby watched the video before getting bored and looking away. When an infant's looking times dropped under a critical threshold, she was tested either with a movie of a new type or with a new instance of the familiar movie type. If infants encode representations of the movies that support the detection of the change between movie types, they will retrieve interest in and look longer at the novel one. Infants looking patterns confirmed our predictions.