Human Infants' Learning of Social Structures: The Case of Dominance Hierarchy

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Abstract
We tested 15-month-olds' capacity to represent social-dominance hierarchies with more than two agents. Our results showed that infants found it harder to memorize dominance relations that were presented in an order that hindered the incremental formation of a single structure (Study 1). These results suggest that infants attempt to build structures incrementally, relation by relation, thereby simplifying the complex problem of recognizing a social structure. Infants also found circular dominance structures harder to process than linear dominance structures (Study 2). These expectations about the shape of structures may facilitate learning. Our results suggest that infants attempt to represent social structures composed of social relations. They indicate that human infants go beyond learning about individual social partners and their respective relations and form hypotheses about how social groups are organized.

Animal species, including humans, recognize social structures, such as social-dominance hierarchies, without formal teaching or supervised training (Bergman, Beehner, Cheney, & Seyfarth, 2003; Boehm, 1999; Fiske, 1992; Grosenick, Clement, & Fernald, 2007; Paz-y-Miño, Bond, Kamil, & Balda, 2004). This capacity is remarkable because the range of possible social structures is extremely vast. For example, n individuals all related to each other could, in theory, form $2^{n(n-1)/2}$ different dominance structures. Assessing the likelihood of each of these theoretical possibilities seems intractable. Instead of this brute-force strategy, we hypothesize that learners use heuristics to discover social structures.

Just as complex problems can be simplified by dividing them into series of smaller problems that can be solved separately (Simon, 1962), dominance structures can be decomposed into sets of dyadic relations. Thus, instead of discovering a complete dominance hierarchy at once, one can construct it incrementally by uncovering dominance relations separately and combining them in a structure. Therefore, we hypothesized that if human infants represent dominance hierarchies, they should find it easier to build such structures incrementally as opposed to nonincrementally (Study 1).

Discovering a structure can also be facilitated by appropriate expectations about its shape. Social-dominance structures are often linear (Boehm, 1999; Caplan, Vespo, Pedersen, & Hay, 1991; Fiske, 1992; Hawley, 1999). Therefore, we hypothesized that if infants have expectations about the shape of dominance structures, they should find linear structures easier to process or more plausible than circular structures (Study 2).

To test these two hypotheses, we presented 15-month-old infants with a looking-time paradigm, capitalizing on infants' tendency to look at a stimulus for a relatively longer duration when previously established dominance relations are reversed rather than confirmed (Mascaro &

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Csibra, 2012; Thomsen, Frankenhuis, Ingold-Smith, & Carey, 2011). We defined *dominance* as the capacity to prevail when two agents have conflicting goals (Hand, 1986; Weber, 1946) and assumed that social structures involve at least three individuals (Flack & Krakauer, 2006).

General Method

Apparatus

Infants were tested in a dimly lit soundproof room in which they were seated on their caregiver's lap 100 cm from a 40-in. LCD monitor on which the stimuli were presented. A hidden camera (temporal resolution = 25 frames per second) recorded infants' looking behavior.

Stimuli and procedure

Caregivers were instructed to close their eyes during the procedure. Each infant was presented with three familiarization movies followed by a test movie, and then three more familiarization movies followed by another test movie. One test movie was *coherent* and the other was *incoherent* (the order of presentation was counterbalanced across participants). Details about counterbalancing are provided in the Stimuli and Procedure section of Supplemental Methods and Analyses in the Supplemental Material available online.

During each familiarization movie, two agents (rudimentary animal figures) competed to occupy a small marked area. The *dominant* agent monopolized the area by repeatedly pushing the *subordinate* agent away (see Video S1 in the Supplemental Material). Each of the three familiarization movies viewed by the infants involved a different pair of agents. In the test phase, infants viewed a movie in which two agents who had interacted in a previously viewed familiarization movie competed to collect one object. In coherent test movies, the previously dominant agent prevailed (see Video S2), and in incoherent test movies, the previously subordinate agent prevailed (see Video S3).

Coding and data analysis

Coding and data analysis are detailed in Coding and Data Analyses section of Supplemental Methods and Analyses in the Supplemental Material. All reported statistics are two-tailed.

Study 1

Several dominance relations can be represented independently (e.g., as A > B and B > C, assuming that ">" denotes a dominance relation and that A, B, and C represent different individuals) or in a single structure (e.g., as A > B > C). To assess which of these two systems infants employ, we varied the difficulty of forming an integrated representation of three relations by adapting a method from studies of adults' reasoning (Ehrlich & Johnson-Laird, 1982; Foos, Smith, Sabol, & Mynatt, 1976; Halford, Wilson, & Phillips, 1998).

We assigned infants to one of two conditions. In the familiarization phase of the continuous-chain condition, infants viewed movies in an order whereby, for example, A dominated B in the first movie, B dominated C in the second movie, and C dominated D in the third movie. In the familiarization phase of the discontinuous-chain condition, infants were presented with the same movies but in a different order (e.g., A dominated B, C dominated D, and B dominated C). During the test phase, we probed infants' memory for the relation between A and B. If infants memorize isolated relations (e.g., A > B, B > C, and C > D), the two conditions should be equally difficult. Alternatively, if infants integrate dominance relations into a single unified structure (e.g., memorizing A > B > C > D), the discontinuous-chain condition should be the more difficult of the two because it requires holding two independent relations in mind (A > B and C > D) and subsequently integrating them with the third relation (B > C). Conversely, in the continuous-chain condition, infants could add one agent to the structure at each step (representing A > B first, then A > B > C, and finally A > B > C > D).

Method

Participants. Two groups of 15-month-old infants participated (continuous-chain condition: $n = 24$, mean age = 467 days, range = 456–481 days; discontinuous-chain condition: $n = 24$, mean age = 468 days, range = 455–480 days).

Stimuli and procedure. In the familiarization phase of the continuous-chain condition, we presented dominance relations in two orders, such that 12 of the infants viewed movies that followed the A > B, B > C, C > D order and 12 infants viewed movies that followed the B > C, A > B, C > D order. In the familiarization phase of the discontinuous-chain condition, although infants were shown the same movies, the order in which B > C and C > D were presented was swapped. This procedure resulted in two orders of dominance-relation presentation in which 12 infants viewed movies that followed the A > B, C > D, B > C order and 12 infants viewed movies that followed the C > D, A > B, B > C order. By counterbalancing orders of presentation during the familiarization phase, we controlled for possible combinations of

serial-position order effects and memory interference. Infants were tested on their memory of the relation between A and B because this relation was presented at the same time point in the two conditions.

Results and discussion

Significantly more infants looked longer at the incoherent test movie in the continuous-chain condition (19 out of 24 infants) than in the discontinuous-chain condition (11 out of 24 infants; $p = .036$, Fisher's exact test). Planned comparisons indicated that infants looked longer at the incoherent test movie than at the coherent test movie in the continuous-chain condition (incoherent test: $M = 17.6$ s, $SD = 9.2$; coherent test: $M = 11.6$ s, $SD = 9.5$; $p = .005$, Wilcoxon signed-rank test) but not in the discontinuous-chain condition (incoherent test: $M = 15.8$ s, $SD = 9.6$; coherent test: $M = 16.0$ s, $SD = 11.1$; $p = .84$, Wilcoxon signed-rank test; see Fig. 1 for mean looking-time durations). Infants' memory for the relation between A and B was better in the continuous-chain condition, compared with the discontinuous-chain condition, arguably because the continuous-chain condition made it easier for the infants to integrate several dominance relations into a single structure (for further evidence, see the Additional Experimental Attempts section of Supplemental Methods and Analyses in the Supplemental Material). Having learned about social relations, infants are then capable of integrating these relations into structures incrementally, relation by relation.
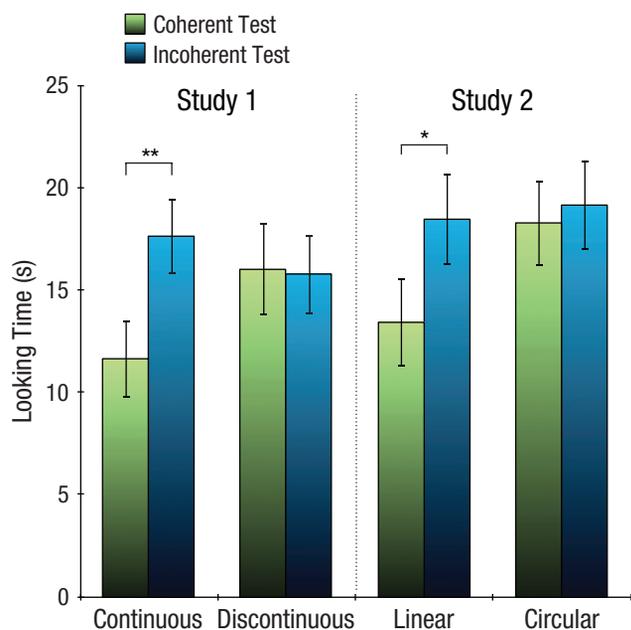
Fig. 1. Results from Studies 1 and 2: mean looking time during test movies as a function of condition and type of test movie. Error bars represent standard errors of the mean. Asterisks indicate significant differences between conditions (*$p < .05$; **$p < .01$).

Study 2

In Study 2, we investigated infants' expectations about the shape of social-dominance structures. Building on studies that have shown that adults find linear structures easier to process than circular structures (De Soto, 1960; Zitek & Tiedens, 2012), we tested whether infants expect dominance structures to be linear. During the familiarization phase of the linear condition, infants viewed movies in which A dominated B, B dominated C, and C dominated D, respectively. In the familiarization phase of the circular condition, infants viewed the same movies except that D was replaced by A and, thus, dominance relations were intransitive: A dominated B, B dominated C, and C dominated A. We then assessed infants' memory for the relation between B and C. If infants find circular dominance structures less plausible or harder to process, their recognition performance should be lower in the circular condition.

Method

Participants. Two groups of 15-month-old infants participated (linear condition: $n = 24$, mean age = 471 days, range = 454–483 days; circular condition: $n = 24$, mean age = 468 days, range = 455–483 days).

Stimuli and procedure. In the linear condition, two orders of presentation were used: A > B, B > C, C > D for 12 participants and B > C, C > D, A > B for 12 participants. In the circular condition, infants saw the same movies in the same order but D was replaced by A. We examined infants' memory for the relation between B and C in the tests of the two conditions. B and C represented both subordinate and dominant agents an equal number of times in the familiarization phase. Thus, it was impossible to recognize the relation between these two agents simply by assessing which agent was more likely to be the "pusher" versus the "pushee," by tracking which agent was the most dominant of all, or by tracking which agent garnered more attention (for further assessment of the effect of attention, see the Attention Allocated to Dominant and Subordinate Agents section of Supplemental Methods and Analyses in the Supplemental Material).

Results and discussion

At the end of the last familiarization movie, infants looked for a significantly longer duration when transitivity was violated in the circular condition compared with when transitivity was not violated in the linear condition (circular condition: $M = 9.18$ s, $SD = 1.50$; linear condition: $M = 7.36$ s, $SD = 2.63$; $p = .012$, Mann-Whitney U test; see details and results of further analyses in the Study 2:

Additional Analyses section of Supplemental Methods and Analyses in the Supplemental Material). The number of infants who looked longer at the incoherent test movie tended to be higher in the linear condition (18 of 24 infants) than in the circular condition (11 of 24 infants; p = .075, Fisher's exact test). Planned comparisons indicated that infants looked longer at the incoherent test than at the coherent test in the linear condition (incoherent test: M = 18.45 s, SD = 11.14; coherent test: M = 13.41 s, SD = 10.68; p = .032, Wilcoxon signed-rank test) but not in the circular condition (incoherent test: M = 19.14 s, SD = 10.94; coherent test: M = 18.27 s, SD = 10.4; p = .84, Wilcoxon signed-rank test; see Fig. 1).[1] The significantly different looking behaviors observed across conditions suggest that infants find circular dominance structures less plausible or harder to process than linear dominance structures. Infants thus have expectations about the configuration of dominance structures. Provided that these expectations are correct, they would facilitate infants' identification of dominance structures.

In Study 2, 15-month-old infants displayed sensitivity to the intransitivity of dominance relations by rejecting circular structures. Yet in Mascaro and Csibra (2012), 15-month-old infants observed A dominating B and B dominating C in one context during familiarization. These infants expected these two relations to be maintained in a novel context. However, there was no evidence that infants formed an expectation about the relationship between A and C in this same novel context. This discrepancy can be explained in two ways. First, in Study 2, the relations that served as potential premises (A > B and B > C) and the relation violating transitivity (C > A) were presented in the same context (in which agents competed to occupy an area). Conversely, in Mascaro and Csibra (2012), the relation violating transitivity was presented in a novel context and thus required infants both to draw a transitive inference and to generalize their expectation across contexts. Second, it is also possible that infants have expectations about, or representational constraints on, the shape of dominance structures without actively drawing transitive inferences. This would explain why, when they witnessed A dominating B and B dominating C, infants displayed no expectations about the relation between A and C in Mascaro and Csibra (2012) but found circular structures harder to process or less plausible in the research reported here.

Infants' sensitivity to transitivity as evidenced in our studies is much more precocious than that evidenced in studies of domain-general reasoning, which have shown no evidence of transitive reasoning before 4 years of age (Bryant & Trabasso, 1971; Piaget, 1947; Wright, 2012). This difference could come (a) from the fact that we tested infants' memory rather than active inferences, (b) from the use of a different method (a looking-time paradigm as opposed to explicit questions), or (c) from earlier development of sensitivity to transitivity in the social-dominance domain compared with other domains (for evidence of a similar discrepancy in the preference-recognition domain, see Mou, Province, & Luo, 2010).

Conclusion

Children participate in social hierarchies from an early age (Caplan et al., 1991; Hawley, 1999). Our findings demonstrate that infants also represent dominance structures using two heuristics: They combine representations of several dyadic relations, and they have expectations about the shape of the resulting structures. It is important to note that our data do not establish whether the mechanisms underpinning infants' representations of structures are domain general or specific to social dominance (for similar issues, see Grosenick et al., 2007; Paz-y-Miño et al., 2004). In particular, future research should investigate the relation between infants' capacity to represent dominance structures and mechanisms supporting representations of "more" and "less" in domains such as number, size, or duration (Brannon, 2002; Fiske, 2004; Lourenco & Longo, 2011).

Dimensions organized on ordered scales, such as number, typically show symbolic distancing effects, such that elements that are farther away on the scale are more easily discriminated (Libertus & Brannon, 2009). Infants' representations of dominance structures have shown the opposite effect. After witnessing A dominating B and B dominating C, infants were less certain about the relation between A and C than about the relations between A and B or B and C (Mascaro & Csibra, 2012). Thus, infants may not represent dominance structures on an ordered scale (e.g., on a line). A directed graph (i.e., a network in which nodes represent agents and edges represent asymmetric relations of dominance) may be a better analogue of infants' representations of dominance structures. This representational format would be more flexible than would an ordered scale. For example, the format would allow for the representation of incomplete structures in which not all individuals are related by dominance relations, such as despotic structures, in which one agent dominates all other individuals but subordinates do not have defined dominance relations.

Our findings are consistent with proposals concerning early development of a "naive sociology" involving conceptual representations of social entities (Kinzler & Spelke, 2007; Mascaro & Csibra, 2012; Platten, Hernik, Fonagy, & Fearon, 2010; Thomsen & Carey, 2013). We found two signatures of the representation of social structures. First, infants' representations of structures were irreducible to a set of isolated representations of dyadic relations. Second, infants expected dominance structures

to have properties that none of the individual dominance relationships can possess, such as linearity. The capacity to combine simple elements into more complex patterned structures is crucial in domains as diverse as language, action planning, and scientific discovery. This capacity is evidenced early in the social domain.

Note

1. Looking times during the test phases of the discontinuous-chain and circular conditions, in which infants may have had low expectations about which agent would prevail, were relatively long and were not unlike looking times during the incoherent tests in the continuous-chain and linear conditions. Thus, in our studies, differences in looking times could have been driven more by facilitated processing of expected events in coherent tests than by violations of expectations in incoherent tests.

References

Bergman, T. J., Beehner, J. C., Cheney, D. L., & Seyfarth, R. M. (2003). Hierarchical classification by rank and kinship in baboons. *Science*, *302*, 1234–1236.

Boehm, C. (1999). *Hierarchy in the forest*. Cambridge, MA: Harvard University Press.

Brannon, E. M. (2002). The development of numerical knowledge in infancy. *Cognition*, *83*, 223–240.

Bryant, P. E., & Trabasso, T. (1971). Transitive inferences and memory in young children. *Nature*, *232*, 458–465.

Caplan, M., Vespo, J. E., Pedersen, J., & Hay, D. (1991). Conflict and its resolution in small groups of one- and two-year-olds. *Child Development*, *62*, 1513–1524.

De Soto, C. B. (1960). Learning a social structure. *Journal of Abnormal and Social Psychology*, *60*, 417–421.

Ehrlich, K., & Johnson-Laird, P. N. (1982). Spatial descriptions and referential continuity. *Journal of Verbal Learning and Verbal Behavior*, *21*, 296–306.

Fiske, A. P. (1992). The four elementary forms of sociality: Framework for a unified theory of social relations. *Psychological Review*, *99*, 689–723.

Fiske, A. P. (2004). Four modes of constituting relationships: Consubstantial assimilation; space, magnitude, time and force; concrete procedures; abstract symbolism. In N. Haslam (Ed.), *Relational models theory: A contemporary overview* (pp. 61–146). Mahwah, NJ: Erlbaum.

Flack, J. C., & Krakauer, D. C. (2006). Encoding power in communication networks. *American Naturalist*, *168*, E87–E102.

Foos, P. W., Smith, K. H., Sabol, M. A., & Mynatt, B. T. (1976). Constructive processes in simple linear order problems. *Journal of Experimental Psychology: Human Learning and Memory*, *2*, 759–766.

Grosenick, L., Clement, T. S., & Fernald, R. D. (2007). Fish can infer social rank by observation alone. *Nature*, *445*, 429–432.

Halford, G. S., Wilson, W. H., & Phillips, S. (1998). Processing capacity defined by relational complexity: Implications for comparative, developmental, and cognitive psychology. *Behavioral & Brain Sciences*, *21*, 803–831.

Hand, J. L. (1986). Resolution of social conflicts: Dominance, egalitarianism, spheres of dominance, and game theory. *Quarterly Review of Biology*, *61*, 201–220.

Hawley, P. H. (1999). The ontogenesis of social dominance: A strategy-based evolutionary perspective. *Developmental Review*, *19*, 97–132.

Kinzler, K. D., & Spelke, E. S. (2007). Core systems in human cognition. *Progress in Brain Research*, *164*, 257–264.

Libertus, M. E., & Brannon, E. M. (2009). Behavioral and neural basis of number sense in infancy. *Current Directions in Psychological Science*, *18*, 346–351.

Lourenco, S. F., & Longo, M. R. (2011). Origins and the development of generalized magnitude representation. In S. Dehaene & E. Brannon (Eds.), *Space, time, and number in the brain: Searching for the foundations of mathematical thought* (pp. 225–244). Amsterdam, The Netherlands: Elsevier.

Mascaro, O., & Csibra, G. (2012). Representation of stable dominance relations by human infants. *Proceedings of the National Academy of Sciences, USA*, *109*, 6862–6868.

Mou, Y., Province, J., & Luo, Y. (2010, March). *Can 16-month-old infants make transitive inferences?* Poster session presented at the International Conference on Infant Studies, Baltimore, MD.

Paz-y-Miño, C., Bond, A. B., Kamil, A. C., & Balda, R. P. (2004). Pinyon jays use transitive inference to predict social dominance. *Nature*, *430*, 778–781.

Piaget, J. (1947). *La psychologie de l'intelligence* [The psychology of intelligence]. Paris, France: Armand Colin.

Platten, L., Hernik, M., Fonagy, P., & Fearon, P. (2010). Knowing who likes who: The early developmental basis of coalition understanding. *European Journal of Social Psychology*, *40*, 569–580.

Simon, H. A. (1962). The architecture of complexity. *Proceedings of the American Philosophical Society*, *106*, 467–482.

Thomsen, L., & Carey, S. (2013). Core cognition of social relations. In M. Banaji & S. A. Gelman (Eds.), *Navigating the social world: What infants, children, and other species teach us* (pp. 88–95). Oxford, England: Oxford University Press.

Thomsen, L., Frankenhuis, W. E., Ingold-Smith, M. C., & Carey, S. (2011). Big and mighty: Preverbal infants mentally represent social dominance. *Science*, *331*, 477–480.

Weber, M. (1946). Class, status, party. In H. H. Gerth & C. Wright Mills (Eds.), *Max Weber: Essays in sociology* (pp. 180–195). Oxford, England: Routledge.

Wright, B. C. (2012). The case for a dual-process theory of transitive reasoning. *Developmental Review*, *32*, 89–124.

Zitek, E. M., & Tiedens, L. Z. (2012). The fluency of social hierarchy: The ease with which hierarchical relationships are seen, remembered, learned and liked. *Journal of Personality and Social Psychology*, *102*, 98–115.