Children's strategic theory of mind

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Human strategic interaction requires reasoning about other people's behavior and mental states, combined with an understanding of their incentives. However, the ontogenic development of strategic reasoning is not well understood: At what age do we show a capacity for sophisticated play in social interactions? Several lines of inquiry suggest an important role for recursive thinking (RT) and theory of mind (ToM), but these capacities leave out the strategic element. We posit a strategic theory of mind (SToM) integrating ToM and RT with reasoning about incentives of all players. We investigated SToM in 3- to 9-y-old children and adults in two games that represent prevalent aspects of social interaction. Children anticipate deceptive and competitive moves from the other player and play both games in a strategically sophisticated manner by 7 y of age. One game has a pure strategy Nash equilibrium: In this game, children achieve equilibrium play by the age of 7 y on the first move. In the other game, with a single mixed-strategy equilibrium, children's behavior moved toward the equilibrium with experience. These two results also correspond to two ways in which children's behavior resembles adult behavior in the same games. In both games, children's behavior becomes more strategically sophisticated with age on the first move. Beyond the age of 7 y, children begin to think about strategic interaction not myopically, but in a farsighted way, possibly with a view to cooperating and capitalizing on mutual gains in long-run relationships.

practical reasoning | child development | game theory

Strategic environments determine outcomes as a function of the decision of many players. Behavior in these environments is directed by a capacity we term strategic theory of mind (SToM), the capacity to infer other people's mental processes and predict their behavior on the basis of knowledge of their incentives and assumption of their rationality. SToM requires two more primitive capacities. The first is "ordinary" theory of mind (ToM), which is a person's ability to "impute mental states to himself and others" (1). The second is recursive thinking (RT), which is the ability to use the output of one step of a reasoning process as input to a following step. In addition, SToM requires that agents reason about the incentives of all involved.

To take an example of the combination of ToM, RT, and reasoning about incentives that will be relevant in the context of this study, suppose that Ann and Bob play a game with rules known to both players, where the rules imply that Ann has an incentive to lie to Bob when Bob believes her. Ann can conclude that she should lie to Bob. Similarly, Bob can conclude that Ann has an incentive to lie to him, and hence he will not believe her. However, in the same manner, Ann concludes that Bob will perform exactly the same reasoning, so that Bob will be skeptical in view of Ann's incentive to lie. Ann will use this output of her reasoning about Bob's incentives as input for her next step of reasoning, and conclude that it is best for her to be truthful instead. A further application of the pattern will suggest that Bob will realize that Ann will perform this reasoning as well, and so on. In each step, the information about the incentives of others is used to predict their actions, given their beliefs and incentives.

Understanding SToM relies on a more subtle distinction within ToM, between the epistemic capacity to understand what others will believe and the practical capacity to understand what others will decide to do in light of their beliefs. In strategic reasoning, a child may need to apply these two types of understanding in sequence. For example, in one of our experiments, if a child attributes to her adult opponent the mistrustful belief that the child will lie (using the epistemic capacity), the child might conclude that the opponent will do the opposite of what the child suggests (using the practical capacity). SToM requires not only that a child be able to answer specific epistemic or practical questions related to ToM but that, without being asked, the child be able to call on answers to such questions recursively to decide what she should do, in light of the incentives applying to all.

The ability to use first-order ToM reasoning flexibly develops at around 3–4 y of age (2–4). The ability to perform RT emerges at a later age [about 7–8 y of age (5)], although the ability to understand recursive notions, such as the successor function and the numbering system, appears earlier (6, 7). Thus, if SToM indeed results from integrating the two capacities, one might expect SToM to emerge at a later age, perhaps substantially later if integrating the two is more complex than using the two in parallel. Although various accounts have been proposed for how first-order ToM develops, second-order developments have received less attention and are less understood (4, 8). Using two strategic games played by children aged 3–9 y, and showcasing different kinds of incentives, we test the hypothesis that SToM results from an integration of ToM and RT, and identify the age at which SToM emerges in children.

Perner and Wimmer (9) show that children demonstrate competence in higher order thinking relating to ToM at the age of 6–7 y. Unlike us, Perner and Wimmer (9) neither study higher order thinking in games nor offer an account of what explains (or supports) the development of higher order thinking. Moreover, such ToM research isolates conceptual developments, giving little attention to how children integrate their conceptual understanding with their practical decisions about how to act in light of considerations about how others will likely act. In philosophical terms, much psychological research targets developments in children's theoretical reasoning but neglects the interaction of theoretical and practical reasoning. A typical first- or second-order false belief task highlights questions about belief (where will X expect the ice cream truck to be?) while making information about goals and actions transparent conditional on those beliefs (where

Significance

Human interaction requires reasoning not only about other people's observed behavior and mental states but also about their incentives and goals. The development of children's strategic thinking is not well understood, leaving open critical questions about early human capacity for strategic interaction. We investigated strategic reasoning in 3- to 9-y-old children and adults in two strategic games that represent prevalent aspects of social interaction: incentives to mislead and competition. We find that despite strategic differences in the two games, by the age of 7 y, children's behavior is similar to that of adults. Our findings also show an early sophisticated ability to think strategically about others in both static and repeated interactions.

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will X look if she expects the ice cream truck to be at Y?). In contrast, in the games used in the current experiment, instead of merely attributing beliefs, participants need to anticipate one another's actions and recognize that those predictions turn on what the other person believes I will do, which, in turn, depends on what the other person believes I believe the other person will do. It is common for children to have information about people's goals, and thus many of their interactions with others, such as siblings, friends, and parents, set the stage for not only theoretical but interactive practical reasoning.

Some papers have studied children playing games with a focus on fairness and trustworthiness (distinct from truthfulness) in ultimatum and trust games (10–12); this literature builds on earlier experimental economics research with children (13–15). Sally and Hill (16) examined the effects of autism on children's performance in games, with a focus on fairness. Other related papers on children's strategic sophistication in games have been written by Perner (17) and Shultz and Cloghesy (18). Perner (17) studies two-by-two games in matrix form, with each containing a dominant strategy for at least one player. In contrast, neither of our games has a dominant strategy, so Perner (17) cannot differentiate, as we do, between games with different levels of strategic complexity.

In the developmental literature on deception, young children are often seen to have difficulty in deceiving others (19, 20) and in interpreting overtly deceptive points from others (21, 22). In the literature on children's ability to mistrust others, children are typically presented with putatively unreliable speakers (of inaccurate, ignorant, and antisocial varieties) (23–25). Notably, in all of this research, children are not asked to consider others' incentives. Thus, we examine how games that contain incentives to be dishonest lead children to mistrust, and to be deceptive themselves. Furthermore, one potential limit of the studies mentioned above is that children are typically asked to perform in only one communicative role: that of sender or receiver of communicative signals.

In our study, the child played the same game both as sender and as receiver. This feature of our design allowed us to examine whether children's strategic reasoning emerges in a similar fashion across these two roles. An additional novelty of our design is that children played two games, each against an experimenter. The two games were chosen because they have completely different game theoretical properties, so they provide an independent test of our hypothesis because ToM and RT operate differently in the two games.

In the sender–receiver game, the child played one of two roles: She was either the sender or the receiver. An experimenter occupied the other role. The sender knows the location of a piece of candy placed in one of two boxes, and the receiver does not. The sender points to one of the boxes, not necessarily the box containing the candy. The receiver then selects a box. If the receiver selects the box with the candy, the receiver keeps the candy; otherwise, the sender gets the candy. As in our introductory example, the sender has an incentive to deceive the receiver if the receiver believes the deception.

In the stickers game, the child and experimenter simultaneously select a number of stickers between one and five. Whoever selects strictly fewer stickers gets to keep her stickers, whereas the other player receives nothing. If both players select the same number of stickers, neither keeps any stickers. Each player has an incentive to undercut the other player by as little as possible: For example, a player who knows that her opponent will select three stickers should select two stickers.

Both the sender–receiver game and the stickers game were played repeatedly, allowing observation of both children's first moves and the subsequent evolution of play. Observation of first moves reveals the outcome of the child's a priori reasoning process, allowing us to draw inferences on the role of SToM therein, and the evolution of this role with age. Observation of subsequent moves reveals the incremental outcomes of the child's learning processes, allowing us to draw inferences about how SToM interacts with learning from experience.

We ran a parallel experiment on adults, which is described in *SI Appendix*, to allow for a comparison between children and adult behavior. *SI Appendix* contains a detailed description of our procedure for children, as well as additional results on children's behavior in later rounds in the two games. In this setting, the specific questions we address are the following. First, at what age do children show evidence of SToM? Second, is the age of acquisition of SToM constant across simple games of different kind, or does it depend on specific properties of the game? Finally, how is the acquisition of SToM modulated by other cognitive capacities, such as working memory?

Strategic Analysis of the Games

There are two important strategic dimensions, widely discussed in the game theoretical literature, along which the two games differ: scope for cooperation and action selection [with the latter corresponding to availability of (iteratively) dominated actions and existence of pure strategy equilibrium].

The sender–receiver game is zero-sum, meaning that the interests of the players are exactly opposed. The zero-sum nature and the symmetry of the game imply that if the players are rational, each will win half of the time on average. Thus, there is no scope for cooperation in the sender–receiver game.

In contrast, the stickers game allows scope for cooperation when repeated. If played once, rational play predicts that each player selects just one sticker (see the discussion of iterated dominance below). In that case, neither player wins anything. If players play repeatedly, however, as they do in our experiment, they can benefit from cooperation: If on each round, one player selected five stickers and the other selected four, and the players alternated between these two roles, each player would then alternate between winning zero and four stickers, winning an average of two stickers per round.

Putting cooperation aside, the game theoretical concept of iterated dominance provides a unique prediction when the game is played once by fully rational players: Both should select just one sticker. This reasoning starts by arguing that no player should ever select five stickers because, regardless of the other's play, selecting five leads to zero winnings for the player who does so. If both players recognize this point and neither selects five stickers, a similar argument shows that neither should select four stickers. Iterating, one concludes that both should select one sticker. The choice of one sticker by each player is also a symmetrical Nash equilibrium. There are two asymmetrical Nash equilibria: In each, one player selects one sticker and the other player selects two stickers. One-shot play makes it difficult to coordinate on one of the two asymmetrical equilibria, especially because each player would prefer the equilibrium where she/he is the one choosing one sticker. Thus, we do not expect to observe these asymmetrical equilibria. In sum, both iterated dominance and symmetrical Nash equilibrium predict one sticker.

In contrast, no simple prediction is possible in the sender–receiver game: The rule prescribing that the sender should tell the truth could be exploited by a receiver choosing the box the sender indicates, and the rule prescribing that the sender should lie could be exploited by a receiver choosing the opposite box. Iterated dominance does not eliminate any possibilities in the sender–receiver game; thus, complete perfectly rational application of ToM and RT leads to no clear prescription in the sender–receiver game. In addition, the sender–receiver game does not contain a pure strategy Nash equilibrium. Rather, Nash equilibrium prescribes not a single action but a probability distribution over actions: Rational players should randomize equally among actions to make it impossible for the opponent to exploit any systematic tendency to choose one action over the other.

In our analysis, we are primarily interested in the first round of play, which isolates children's ability to reason about the game before play. The optimal rational reasoning processes described above used ToM and RT extensively. Thus, we do not expect all children to behave according to that prescription. The youngest children are likely to play naively; as they age, we expect children to apply recursive thinking at successively higher levels. We assume that at each stage in their reasoning, children best respond to their beliefs about opponents' play, meaning that children choose the action that is best in light of their beliefs.

In the sender–receiver game, this analysis implies that children, as they age, will move along the following series of steps. Each substep below labeled (*a*) involves a use of ToM in which the child comes to understand what the other player will believe and do, and each substep labeled (*b*) involves a decision of the child about what to do in light of her beliefs about the other player:

i) Children play naively, reporting truthfully as sender and trusting as receiver.

ii) (*a*) Children realize that the other player will play naively as in step *i*.
(*b*) Children best respond to belief *ii* (*a*), lying as sender and trusting as receiver.

iii) (*a*) Children realize that the other player will reason and play as in step *ii*.
(*b*) Children best respond to belief *iii* (*a*), lying as sender and mistrusting as receiver.

It is possible that older children will iterate the above reasoning process beyond step *iii*, or even that they will eventually realize that there is no end to the process and also realize that their opponent will come to this conclusion. This reasoning may cause children to converge to randomization as in the fully rational benchmark to prevent their opponent from exploiting any systematic behavior that they would otherwise exhibit. In summary, the implications of the assumption that as they age, children will move along the sender–receiver reasoning sequence are as follows: *I*) Lying as the sender increases with age. This implication follows because lying occurs in steps *ii* and *iii*, but not in step *i*. *II*) Mistrusting as the receiver increases with age. This implication follows because mistrusting occurs at step *iii*, but not at step *i* or *ii*. *III*) A more subtle implication is that children start lying before they start mistrusting. This implication follows because lying starts at step *ii*, whereas mistrusting starts only at step *iii*. A moral, rather than strategic, theory of behavior, assuming that younger children are inhibited from selecting immoral actions, would make a prediction opposite from that in *III*, namely, that children mistrust at a younger age than that at which they lie. The reason is that one can only gain from lying if the opponent is trusting (i.e., moral), whereas one can gain from mistrusting only if the opponent is lying (i.e., immoral). In the latter case, the (perceived) immorality of the opponent may release one from one's own moral obligation, whereas in the former case, lying exploits the moral behavior of one's opponent.

For the stickers game, we conjecture that children, as they age, follow a reasoning sequence parallel to the one we conjectured for the sender–receiver game:

i) Children play naively, selecting five stickers, the maximum possible number.

ii) (*a*) Children realize that the other player will play naively as in step *i*.
(*b*) Children best respond to belief *ii* (*a*), selecting four stickers.

iii) (*a*) Children realize that the other player will reason and play as in step *ii*.
(*b*) Children best respond to belief *ii* (*b*), selecting three stickers.

iv) Children either continue iterating the above until they reach one sticker or "jump" to one sticker, realizing where the process is heading.

This sequence assumes that children begin with five stickers. Given the rules of the stickers game, choosing five stickers can never lead the child to win any stickers, regardless of the choice of the other player. In other words, the choice of five stickers is weakly dominated by any choice of strictly fewer stickers. This reasoning about the choice of five stickers does not require ToM but only requires knowledge of the rules of the game. Although this inference is likely to be too difficult for the youngest children, it is worth noting that the qualitative features of the stickers reasoning sequence would not change if we assumed that naive play at step *i* consists of choosing four, rather than five, stickers.

The implications of the assumption that, as they age, children will move along the stickers reasoning sequence are as follows: (I') The number of stickers declines with age, and (II') the number of stickers eventually converges to one.

Experimental Results

In all tables, the P value is indicated as follows: $^{*}P < 0.1$; $^{**}P < 0.05$; $^{***}P < 0.01$.

Total sample size was 69, and mean age was 5.99 y (SE = 0.19); the minimum age was 3.3 y, and the maximum age was 8.83 y. The age distribution of children was approximately uniform (*SI Appendix*, Fig. S1). Thirty-six children (52.1%) were male.

As a proxy for intelligence, we measured working memory by administering an n-backward task (26). We find that performance substantially improves with age. *SI Appendix*, Fig. S2 suggests that approximately one additional item is remembered with 2 additional years of age, until 7 y of age. We gave children a maximum number of five items to recall; thus, the flat performance for older children is, at least in part, due to this fact. *SI Appendix*, Table S1 estimates the gain per year as 0.45. There is no significant sex effect in n-backward task performance.

Stickers Game. Fig. 1 shows the change in the numbers of stickers played in first move as age progresses. The number, as predicted, steadily declines with age. Most of the youngest children (aged less than 4 y) play the maximum number of five stickers. The estimated local average [locally weighted scatterplot smoothing (LOWESS)] reaches the minimum of one sticker by the age of 6.5 y. Fig. 1 shows that in the age interval of 6.5–8 y, all children in our sample choose only one sticker. Table 1 shows an estimated average reduction of the number of stickers played of ∼0.4 stickers per year of age. There is no significant sex effect or an interaction between sex and age. There is a large and significant effect of intelligence, or working memory, as measured by the score in the n-backward task: A higher score is associated with a smaller number of stickers played. The score in the regression reported in Table 1 is normalized between 0 and 1; thus, the total effect from maximum to minimum score is a reduction of 2.4 stickers over five stickers.

The choice of a single sticker by both players is the unique iterated dominance solution in the game. Our data are consistent with the hypothesis that children follow the iterated reasoning

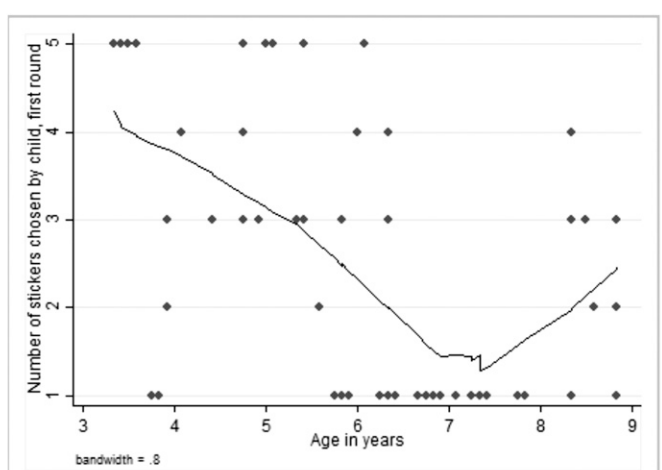

Fig. 1. First move in the stickers game. The number of stickers chosen by the child in the first move of the game and age of the child are shown. The continuous line is the locally weighted scatterplot smoothing (LOWESS).

Table 1. Number of stickers in the first move of the stickers game: Ordinary least squares

	1 B/SE	2 B/SE	3 B/SE	4 B/SE
Age	−0.510***	−0.403***	−2.465***	−1.597**
	(0.098)	(0.145)	(0.692)	(0.705)
Age squared			0.174***	0.128**
			(0.057)	(0.056)
Male		1.858	2.254*	1.807
		(1.215)	(1.150)	(1.139)
Male × age		−0.227	−0.306	−0.272
		(0.195)	(0.186)	(0.180)
n-backward score				−0.603***
				(0.171)
Constant	5.584***	4.714***	10.390***	8.942***
	(0.610)	(0.875)	(2.042)	(2.027)
N	67	7	67	65

The *n*-backward score is normalized in the unit interval. Age is in years. SEs are provided in parentheses. *$P < 0.1$; **$P < 0.05$; ***$P < 0.01$.

process described above. Thus, an understanding of equilibrium behavior, or behavior implied by iterated dominance, grows with age and is complete by the age of 7 y. However, after the age of 8 y, there is a clear trend for children to play a larger number of stickers, with an average of ∼2.5 stickers at an age older than 8 y. A plausible explanation of this behavior is that children understand that the equilibrium behavior in the single-shot game leads to a zero payoff for both; thus, the cost of deviating from the equilibrium is small. In addition, the possibility of cooperation of some form between the two players (e.g., by randomly playing a number of stickers larger than one) makes the choice of a number of stickers larger than one preferable. Such cooperation could be profitable to both players, given that play is repeated over several rounds.

Sender–Receiver Game. In the sender–receiver game, children were randomly assigned to play either the sender role or the receiver role first. Fig. 2 reports the children's choices by age in years. To make the choices in sender and receiver roles easily comparable, we label the choice of deception (in the role of sender) and mistrust (in the role of receiver) as 1, and the opposite choice as 0. This variable can be interpreted as a deception/mistrust index. In Fig. 2 (*Upper*), children's first moves in whichever role (sender or receiver) the child played first are shown, and in Fig. 2 (*Lower*), the first move in the second role is shown; the first moves as sender (Fig. 2, *Left*) and as receiver (Fig. 2, *Right*) are separately shown.

In Fig. 2 (*Upper*, first move in first role), there is a clear upward trend, going from fully truthful behavior for senders and fully trusting behavior for receivers among the youngest children to deception and mistrust among the oldest. There is a slight trend downward for older ages in the receiver role, moving toward the equilibrium choice of 50%. Unlike the stickers game, in the sender–receiver game, iteration of inferences does not lead to an equilibrium; thus, behavior is unlikely to settle down. As children play, learning and observation of the other's behavior substantially modifies a child's own behavior. Fig. 2 shows that when children play the game in their second role, having already observed the other player when playing in the other role, their behavior is muted and less extreme. In particular, younger children deceive/mistrust more often and older children tell the truth/trust more often. In Fig. 2 (*Lower*, first move in second role), the trend is flatter and not clearly monotonic.

Table 2 presents the linear probability model for the first move in the first role, so coefficients indicate the effect size (logit regressions are reported in *SI Appendix*, Table S2). The regressions confirm a significant change of an increase of ∼13–15% in the fraction of deceiving and mistrusting behavior for every year of age. There is no significant effect of sex or intelligence. As age increases, children appear to take the first steps in the strategic reasoning process (see *Strategic Analysis of the Games* above) according to which one should deceive against a trusting opponent and one should mistrust against a deceptive opponent. There is a significant additional effect from the quadratic term for age, indicating that for older children, the overall effect of age is reduced [as is also clear in Fig. 2 (*Upper Right*) for children playing as receiver].

To estimate the effect of experience, we compare first-round choices when children played the game for the first and second times in opposite roles. The second time variable is equal to 1 in the second time observation, and is 0 for the first. Results for the random effect linear model are presented in Table 3 (the logit regression is shown in *SI Appendix*, Table S3). Age interacts with experience: Moving from the first to the second role leads to a

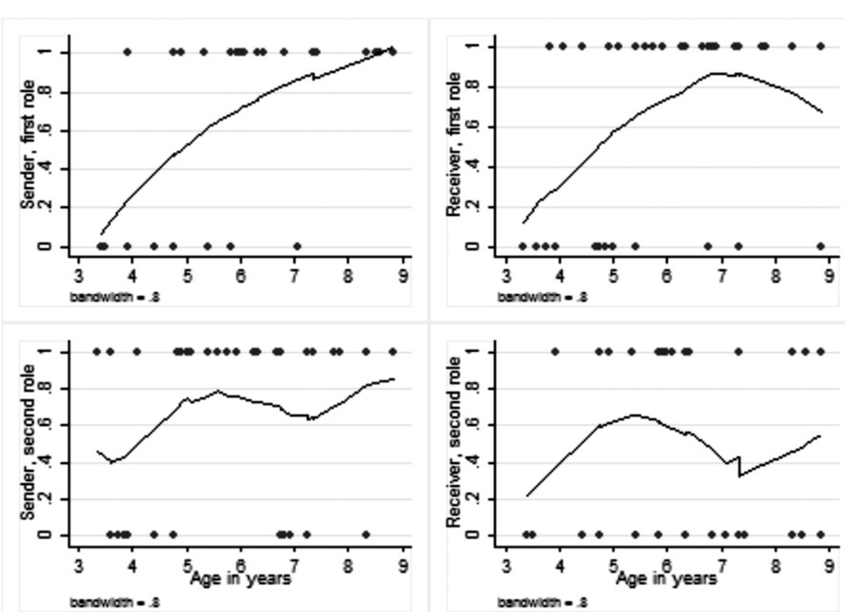

Fig. 2. First move in the sender–receiver game. The variable on the vertical axis is equal to 1 if the child deceives in the role of sender and mistrusts in the role of receiver; it is 0 otherwise. (*Upper*) First move in the rounds where the child played the game the first time and age (in years) of child. (Lower) First move in the rounds where the child played the game the second time. (*Left*) Move as sender. (*Right*) Move as receiver. The continuous line is the LOWESS.

Table 2. Deception and mistrust index in sender-receiver game: Ordinary least squares

	1 B/SE	2 B/SE	3 B/SE	4 B/SE
Age	0.141***	0.127***	0.648***	0.659**
	(0.032)	(0.046)	(0.228)	(0.260)
Age squared			−0.044**	−0.045**
			(0.019)	(0.021)
Male		−0.502	−0.643*	−0.716*
		(0.389)	(0.381)	(0.424)
n-backward score				−0.114
				(0.307)
Male × age		0.044	0.070	0.080
		(0.062)	(0.061)	(0.066)
Constant	−0.180	0.019	−1.417**	−1.362*
	(0.199)	(0.276)	(0.671)	(0.742)
N	67	67	67	64

The dependent variable is equal to 1 if the child deceives in the role of sender and mistrusts in the role of receiver; it is 0 otherwise. Only observations in which subjects played the game for the first time are considered. The *n*-backward score is normalized in the unit interval. Age is in years. SEs are provided in parentheses. $*P < 0.1$; $**P < 0.05$; $***P < 0.01$.

greater movement toward deceive/mistrust among younger children than among older children. The younger children move away from their starting point of playing trust/truth most of the time, and, similarly, the older children move away from their starting point of deceive/mistrust. The overall effect among both younger and older children is that a movement from the first role to the second role causes children to be more deceptive/mistrusting.

Comparison with Adults. We compare children's behavior with that of adults (mean age = 21.4 y) in the same (although differently presented) games. In the adult version of the stickers game, almost all adults chose the number 1 or 2 (which, for the winner, was converted to dollars rather than stickers): In the first move, the mean choice was 1.81 (SE = 0.11). *SI Appendix*, Fig. S6 reports the number chosen in the first move for children younger than 7.5 y of age; then, for the others; and, finally, for the adults. Although no adult subject chose the number 5, a substantial number chose the number 2. Like adults, most children over 6.5 y of age chose either one or two stickers. In contrast, children younger than 6.5 y of age chose a larger number of stickers (Fig. 1). As we discuss in next section (*Discussion*), there is a difference between children younger than 8 y of age and children older than 8 y of age, but both of these groups are more similar to adults than children younger than 6.5 y of age.

In the adult version of the sender–receiver game, adults play the deceiving/mistrustful first move 43% of the time (n = 44), whereas children chose the deceiving/mistrustful first move 67% of the time (n = 67). For comparison, consider the LOWESS for children reported in Fig. 2. For children younger than 5.5 y of age, deceit/mistrust was chosen 38% of the time (n = 26); for children between 5.5 and 7.5 y of age, deceit/mistrust was chosen 85% of the time (n = 29); and for children older than 7.5 y of age, deceit/mistrust was chosen 80% of the time (n = 12). The youngest children chose the deceiving/mistrustful moves more rarely than adults. As age increases, the faction choosing the deceiving/mistrustful move grows until the older children choose this move more often than adults. Thus, the first-round behavior of the oldest and youngest children in the first role is more predictable than that of adults. In contrast, in the second, more experienced role, children's first-round behavior becomes more unpredictable and adult-like.

Discussion

Children appear to acquire SToM by the age of 6–7 y, as evidenced by a tendency to select sophisticated actions on the first move. In our data, this tendency holds in both games despite significant game theoretical differences. The stickers game has an incentive for cooperation, because taking turns in selecting a high number of stickers or randomizing in every round would lead to a higher payoff than the equilibrium of the one-shot game. In contrast, the sender–receiver game is a zero-sum game and provides no scope for cooperation even in repeated interaction. The stickers game can be solved by iterated dominance, and the sender–receiver game cannot; the unique mixed equilibrium of the sender–receiver game cannot be reached through iterated dominance. Our data are consistent with the view that as they age, children apply continually higher levels of recursive thinking, following the reasoning sequences presented in *Strategic Analysis of the Games* above, and conforming to implications (*I–II*) in the sender–receiver game and implications (*I′–II′*) in the stickers game. Such first-move sophistication shows that children apply strategic reasoning when given only information about incentives, before any feedback.

In the sender–receiver game, the process does not converge to a pure strategy Nash equilibrium because none exists; the mixed strategy equilibrium is much harder to understand and estimate precisely. Two findings speak to mixed strategy play in children. First, Table 3 shows that younger children move from playing truth/trust to sometimes playing deceive/mistrust and the older children move from playing deceive/mistrust to sometimes playing truth/trust. This pattern is consistent with the view that in the first role, children play a pure strategy, but with more experience in the second role, they move toward mixed strategies. Second, over multiple rounds, *SI Appendix*, Fig. S5 shows that play becomes more concentrated around equal probability randomization as children age. It is, however, difficult to separate randomization from alternation in response to the experimenter's last move. Senders are responsive to the experimenter's last move, whereas receivers are minimally so. Note that senders tend to choose the move that is not a best response to the experimenter's last move. For senders, responsiveness to the last move becomes more muted with age, suggesting an increase in randomization (all of the above results are shown in *SI Appendix*, Tables S7–S10).

A comparison of child and adult behavior reveals important similarities. First, in the adult analog of stickers, adults tend to select a small number (1 or 2), and children move from a large number to a small number with age. Second, adults do not exclusively choose 1, just as the oldest children (aged 8 y and older) do not exclusively choose 1. Third, in the sender–receiver game, adults do not overwhelmingly choose the sophisticated or naive action but rather mix their play, both on the first and later moves. Children do not appear to mix on their first move in their first role but tend to move toward mixing with experience as detailed above.

Table 3. Choice in first round, for the first and second times a child played the game: Random effects linear model, robust SEs

	1 B/SE	2 B/SE	3 B/SE	4 B/SE
Second time	−0.075	−0.075	0.609**	0.609**
	(0.075)	(0.075)	(0.282)	(0.283)
Age		0.084***	0.141***	0.591***
		(0.025)	(0.031)	(0.177)
Age × second time			−0.113**	−0.113**
			(0.047)	(0.047)
Age squared				−0.037**
				(0.014)
Constant	0.672***	0.162	−0.180	−1.451***
	(0.058)	(0.177)	(0.201)	(0.519)
N	134	134	134	134

The variable second time is the indicator of the trial in which the subject played the game for the second time. Age is in years. SEs are provided in parentheses. $*P < 0.1$; $**P < 0.05$; $***P < 0.01$.

One developmental explanation for the gradually increasing sophistication is an increasing capacity to perform more steps of RT. Support for this explanation comes from the finding of Perner and Wimmer (9) that children demonstrate competence in higher order thinking at the age of 6–7 y, which is precisely when children demonstrate strategic sophistication in our experiments. Further support derives from the finding that strategic play in the stickers game was correlated with children's working memory performance. An alternative explanation is development in either the epistemic capacity to attribute beliefs to others in response to incentives or the practical capacity to transition from attributed beliefs to attributed actions. Indirect support for the failure of the practical capacity comes from experiments showing that children may recognize faulty beliefs in others early, although failing to use this knowledge to anticipate the other's surprise (27), actions such as false statements (28), or emotional reactions (29) correctly. Future experiments should discriminate the contributions of children's developing recursive reasoning, epistemic understanding, practical reasoning, and more general factors (e.g., behavioral control) (30, 31).

The analysis of stickers presents a particularly interesting finding. Between the ages of 6.5 and 8 y, all children select one sticker, the smallest possible number, in the first round. This choice is the most sophisticated move for a player who considers each round in isolation. Younger children progressively reduced the number of stickers with age. However, after the age of 8 y, children begin to select a larger number of stickers. This outcome suggests a possible cooperative motive if children view the game as a repeated interaction and recognize that both players can benefit if each gets a chance to win in different trials. Call this interpretation the collusive interpretation. A different feigning interpretation is that older children select a higher number of stickers to fool the opponent into thinking that they will do so again, allowing the child to undercut the opponent later. Both collusion and feigning posit that the oldest children become farsighted, viewing the game as a multiple-round affair, but collusion is cooperative and feigning is deceptive. The distinction between one-shot and repeated play is important in the game theoretical literature. Future research should focus on children's developing capacity to perceive interactions more broadly as repeated rather than one-shot.

There are several additional promising directions for future research. In experiments with two children playing against each other, we could examine whether the movement toward mixed strategies in later rounds of the sender–receiver game replicates. In a two-child version of stickers, the oldest children might actually achieve the higher payoff collusive outcomes that they seem to signal in the early rounds of our experiments. Another relevant experiment would have children play only one round (against an experimenter) and explicitly tell them they will play only one round. If a farsighted interpretation is correct, the oldest children should choose only one sticker in this version. This potential outcome, however, would not discriminate between the collusive and feigning interpretations, which are both farsighted. To separate these explanations, one could run another multiple-round experiment and ask children to explain their choices, with an interest in whether they offer "collusive" or "feigning" justifications.

This paper has explored an important understudied aspect of child development: children's ability to reason strategically, predicting others' behavior on the basis of knowledge of incentives, and adjusting to it. We focused on competition and incentives to mislead, two prevalent aspects of the environment to which children must adapt. Children demonstrate strategic sophistication at a surprisingly young age, and even appear to be able to think about interaction in a farsighted manner, considering the ramifications of the current game on the game to follow.

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Children's Strategic Theory of Mind

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Supporting Information

S1 Procedure for Children

S1.1 Sample selection and implementation

The sample was randomly selected from a database consisting of children from Minneapolis. Children from this pool are predominantly Caucasian, native English speakers from middle to high SES homes.

Families received a $10 gift card in compensation for their participation.

Each child participated in 3 tasks in the following fixed order: a Backwards Word Span task; the Sender-Receiver game and the Stickers game. The entire experiment lasted approximately 30 minutes.

Each adult participated in 3 tasks in the following fixed order: the Sender-Receiver game, an N-Back Shape Memory Task and the Circles Game (an adult analogue of the Stickers Game). The entire experiment lasted approximately 65 minutes.

S1.2 n-Back Task: Word Memory Task

To obtain a measure of children's working memory, each child was asked to repeat a list of words in backwards order. The experimenter presented a puppet (named "Harold") with the following introduction: "I have a game where we say things backward. Here's Harold. Harold's always being silly so whatever I say, he says backward. Like this: If I say the words "book, cup", Harold says, "cup, book." Isn't that silly? If I say, "ball, duck", Harold says, "duck, ball". Now you try (Harold is taken out of view). Whatever I say, YOU say it backward, OK?

The practice list contained two words and if needed, correction was given for up to four tries. If the child did not produce the correct response within four tries, the highest level completed was scored as 1. After the practice list was given, the test lists were presented and the experimenter provided a reminder, "Let's do some more like that. Remember, whatever I say, you say it backward." The first test list contained 3 two-word spans (Level 2) and each subsequent list gradually increased

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(Level 3: three-word span, Level 4: four-word span) to a Level 5 list containing 3 five-word spans. The interviewer stops administering the measure after three consecutive failures and reported the highest level passed without erring. Thus, a score of one was given if (1) the child failed the practice trials, or (2) passed the practice trial, but failed the first test list. In all other cases, the score on this item represents the highest number of words the child was able to repeat accurately. We chose a measure of working memory given evidence that working memory at age 5 better predicts academic performance at age 11 than IQ, measured at age 5 or 11 (1).

S1.3 Sender-Receiver Game

The experimenter (E2) escorted the child into a new room and seated the child at a table across from an adult player (E1). On the table sat two boxes.

Instructions. In order to confirm that each child possessed a firm understanding of the incentives involved in this game, E2 presented children with clear instructions on the rules of the game and also gave both players the opportunity to practice the game (practice trials), both aspects of the procedure are described below. Instructions: "I am going to show you both how to play a game called, "How to get the treat." Do you see the boxes on the table? They are used in this game. First, I am going to hide a treat in one of the boxes [E2 showed players the treat] and a rock in the other box [E2 showed players the rock]. We will play for stickers first, and then later we'll play for candy. Please close your eyes!" After hiding the treat and rock in each of the boxes, E2 asked the child, "Can you show me where the sticker is?" Practice trials: Across 9 practice trials, the child and the other player, E1, took turns guessing about the location of the sticker. On each practice trial, correct guesses were rewarded by receiving the sticker in the box and incorrect guesses were punished by awarding the sticker to the opposite player. After the practice trials, children were asked two comprehension questions: "If you pick the box with the treat inside, who gets the treat?" and "If you pick the box with the rock inside, who gets the treat?" If the child demonstrated a lack of comprehension on either of these questions, three additional Practice trials occurred and the child's comprehension was rechecked.

Test trials. The test trials were defined by the same rules as the practice trials with one main difference - on test trials, after E2 baited the containers, the main players (child and E1) in alternate blocks of trials were allowed to signal the location of the candy by placing a wooden block on top of one of the two boxes.

Children were randomly assigned to two main ordered conditions: Receiver First in which children received signals from E1 in the first block of trials and sent signals to E1 on the second block of trials (R, S) or Sender First in which children sent signals to E1 on the first block of trials and received signals from E1 in the second block of trials, (S, R).

To begin the test trials, E2 said, "Great, now we are going to play for candy (E2 presents bag of candy)! Do you see this block?" When the child was to play the sender role, E2 said, "I am going to give this block to you now and you can put it on one of the boxes. Then E1 gets to guess which box the candy is in. Close your eyes!" When the child was in the receiver role, E2 said "I am going to give this block to E1 now and you can put it on one of the boxes. Then you get to guess which box the candy is in. Close your eyes!" Each test trial began when Experimenter E2 hid a candy in one box, and the rock in the other. When the child played the role of Receiver, E2 positioned the open ends of the boxes in plain view of E1. When the child played the role of the Sender, E2 positioned the open ends of the boxes in plain view of the child. Children participated in a total of 12 test trials, 6 in the role of Receiver and 6 in the role of Sender.

Experimenter strategy. Recall that in the one shot game the best response as sender to mistrust is truth, and to trust is deception; as a receiver, the best response to truth is trust, and to deception is mistrust.

When E1 was in the role of sender and the child was in the role of receiver, the experimenter lied in the first trial, and then chose in each trial the best response to the choice of the child in the previous trial. Specifically, in the first trial E1 placed the block on the container not containing the candy. On subsequent trails, E1 placed the block on the box containing the rock if in the previous trail, the child selected the box that E1 indicated with the block, and placed the block on the box containing the candy if in the previous trail, the child selected the box E1 did not indicate with the block.

When E1 was in the role of receiver and the child was in the role of sender, the experimenter trusted in first trial, and then chose in each trial the best response to the choice of the child in the previous trial. Specifically, on the first trail, E1 selected the box on which the child placed the block. On subsequent trails, E1 selected the box the child indicated with the block if on the previous trail, the child placed the block on the box containing the candy, and E1 selected the box the child did not indicate with the block if on the previous trail the child placed the block on the box containing the rock.

S1.4 Stickers Game

As in the Sender-Receiver game, the child participated as one of two players with E1. E2 introduced the game by saying, "Now we're going to play a game called "Sticker Contest". I'm going to give you and E1 each a basket and 5 stickers. You can put however many stickers you want to into the basket: 1, 2, 3, 4, or 5! After you do that, I am going to look in your baskets and count your stickers." Rules: "If you put a smaller number of stickers in your basket, then you get to keep your stickers and E1 doesn't get any. But if E1 has a smaller number of stickers in her basket, then she gets to keep her stickers and you don't get any. If you and E1 have the same number of stickers, then no one keeps their stickers." The Stickers Contest was played for 10 rounds. The number of rounds was not stated at the beginning of the experiment. Total amount of stickers won across the 10 trials was coded for each participant. On the first trail, E1 selected 4 stickers. On subsequent trails, E1 selected one less sticker than the child selected on the previous trail, unless the child selected 1 sticker on the previous trail, in which case E1 selected 1 sticker.

S2 Procedure for Adults

S2.1 Sample selection and implementation

Adult participants were college students recruited from a large introductory economics course at the University of Minnesota. The final sample of adults contained 44 subjects, average age 21.4 years. The experiment was run at the University of Minnesota Social and Behavioral Sciences Laboratory. Three sessions were conducted, each of which contained approximately 20 subjects. For one of the sessions, because of a computer crash we could not collect complete data. We exclude this session from the analysis. Each subject was seated at a computer in a private cubicle. Subjects received $10 for participation and an additional amount which varied between $0 and $31.80 depending on their performance in the experiments. Participation was voluntary.

The experiment was performed in a computer lab. Subjects were seated at computer terminals in private cubicles. Subjects performed three tasks in the following sequence:

1. the Sender-Receiver Game (corresponding to the Sender receiver game played by children)
2. the N-back memory task,
3. the Circles Game (the adult analogue of the stickers game).

Subjects received $10 for participation and an additional amount which could vary between $0 and $31.80 depending on their performance in the experiments, as described below.

S2.2 n-Back Task: Shape Memory Task

In this task subjects were shown a sequence of shapes and were asked to indicate whether each shape matched the shape before the previous shape. Subjects had the opportunity to answer a total of 48 times. Subjects won $0.10 per correct answer, and so had the potential to win between $0 and $4.80 on this task.

S2.3 Sender-Receiver Game

Subjects played both the sender role (in the sender condition) and the receiver role (in the receiver condition) in the Sender-Receiver game. All subjects played both roles. Half of the subjects played the sender condition first and the receiver condition second, and the other half played the receiver condition first, and the sender condition second. Subjects were randomly assigned to the two groups.

The instructions in the sender condition were:

> “This experiment deals with the following scenario, which involves an interaction between you and another player. There are two envelopes. One envelope contains a dollar. The other envelope contains nothing. You will be shown which envelope contains the dollar using a visual display such as the following:” An image displayed two envelopes, one on the left containing a dollar and the other on the right empty. The instructions continued: “This means that in this case, the dollar is in the envelope on the left. In the actual experiment, you may be shown that the dollar is on the left or that the dollar is on the right. The other player does not know which envelope contains the dollar. You must send a message to the other player which claims that the dollar is in one of the envelopes. You are allowed to claim that the dollar is in either envelope. To send the message, you will click on one of the envelopes. After receiving your message, the other player will guess which envelope contains the dollar. If the other player guesses correctly, s/he will get the dollar and you will get nothing. If the other player guesses incorrectly, s/he will get nothing and you will get the dollar. You will play this game several times against the same other player.”

The instructions in the receiver condition were:

> “This experiment deals with the following scenario, which involves an interaction between you and another player. There are two envelopes. One envelope contains a dollar. The other envelope contains nothing. You will not be shown which envelope contains the dollar. However the other player knows which envelope contains the dollar. The other player will send you a message claiming that the dollar is in one of the envelopes. When the money is in the right envelope, the other player is allowed to claim that the money is in the right envelope and also is allowed to claim that the money is in the left envelope. Similarly, when the money is in the left envelope, the other player is allowed to claim that the money is in the left envelope and also is allowed to claim that the money is in the right envelope. You will see a visual display such as the following:” An image displayed two envelopes. An arrow pointed to the left envelope with a caption: “Your opponent says the dollar is in this envelope.” The instructions continued: “This means that in this case, the other player claims that the dollar is in the envelope on the left. In the actual experiment, the other player may claim that the dollar is on the left or that the dollar is on the right. You must guess which envelope actually contains the dollar. To do so, you will click on an envelope. If you guess correctly, you will get the dollar, and the other player will get nothing. If you guess incorrectly, you will get nothing and the other player will get the dollar. You will play this game several times against the same other player.”

Each condition was played for six rounds. The rules were as described in the instructions. After each round, the computer announced the result of the round (i.e., the opponent’s choice, who won, and in the receiver condition, the true location of the dollar). Actual payments for this game were as described in the instructions, so that subjects could win between \$0 and \$6 in the sender condition, and also could win between \$0 and \$6 in the receiver condition.

The instructions referred to the subject's opponent as "another player," but in fact, the subject played against a computer that was programmed to play in a specific way. On the first move in the sender condition, the computer was programmed to trust the subject, meaning that the computer selected whichever envelope the subject pointed to. On the first move in the receiver condition, the computer was programmed to deceive the subject, meaning that the computer pointed to the envelope not containing the dollar. These first moves were chosen so that if the subject anticipated them, her/his best response on the first move would have been the "sophisticated" or "strategic" move: deceive in the sender condition and mistrust in the receiver condition. The moves of the computer in subsequent rounds were conditional on the subject's previous move. In particular, in both sender and receiver conditions, the computer's move was chosen as the best response to the subject's previous move. This means that in the sender condition, if the subject was truthful in the previous round, the computer trusted the subject in the current round, and if the subject was deceptive in the previous round, the computer mistrusted the subject in the current round. In the receiver condition, if the subject trusted the computer in the previous round, the computer was deceptive in the current round, and if the subject mistrusted the computer in the previous round, then the computer was truthful in the current round. The computer's strategy was the same as the one the experimenter used against the child in the children's Sender-Receiver experiment.

S2.4 Circles Game

The Circles Game was the adult analogue of the Stickers Game for children. Subjects were given the instructions:

> ”This experiment deals with the following scenario, which involves an interaction between you and another player. Both you and the other player will be given an opportunity to pick a number between 1 and 5. To do so, you will be shown the following:" An image displayed five circles, labeled 1 through 5. The instructions continued: "You will click on a circle. Both you and the other player will make your choices simultaneously. So you will not know the other player's choice when making your choice. If you and the other player choose different numbers, the player choosing the smallest number will get a number of dollars equal to the number s/he selected. The player choosing the largest number gets nothing. If both players choose the same number, both players get nothing. You will play this game several times with the same other player. This is also the same player with whom you played the previous games."

Subjects played 10 rounds of the Circles Game. As in the Sender Receiver game, subjects were in fact playing against the computer. The computer selected the number 4 on the first round, and as in the Sender Receiver Game, the Computer selected the best reply to the subject's move on the previous round. This means that the computer selected a number one less than the subject's selection on the previous round. The one exception is when the subject selected 1 on the previous round. In this case, every number is a best reply to the subject's previous move, since every number yields a payoff of zero when the opponent chooses 1. In this case the computer selected the number 1. The computer's strategy was the same as the one the experimenter used against the child in the children's Stickers experiment. Payments were as described in the instruction above. Given the computer's strategy, it was possible for subjects to win between $0 and $15 on this task.

S2.5 Survey

At the end of the experiment, a brief survey about the Circles Experiment was administered. The questions on the survey were:

1. What were you expecting the other to choose?

2. What was the reasoning behind the choice you made?

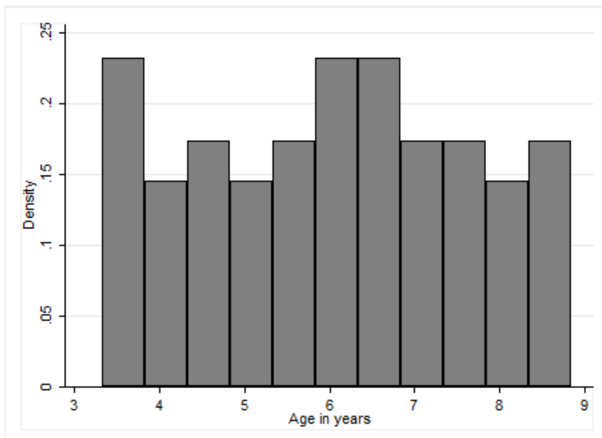
3. Did your strategy change over the course of the task?

S3 Additional Statistical Analysis

In all tables, the p-value is indicated as follows: $^{*}: p < 0.1$;$^{**}: p < 0.05$;$^{***}: p < 0.01$

S3.1 Statistics of the sample

Figure S1: **Distribution of age (in years) of children in the sample**



n-Backward task

Figure S2: **Performance in the n-back task and age (in years): lowess.**

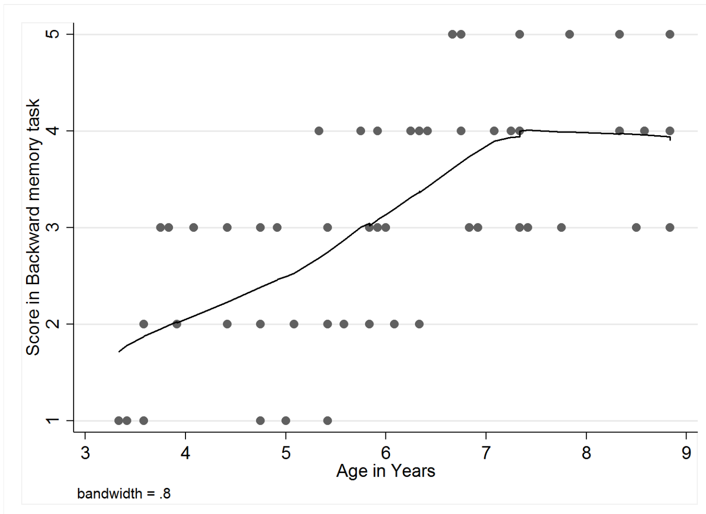


Table S1: **Performance in n-Back task: OLS.** The dependent variable is the score in the n-backward test.

	(1)	(2)	(3)
	b/se	b/se	b/se
Age in years	0.487***	0.458***	1.228**
	(0.069)	(0.100)	(0.510)
Age in years, squared			–0.065
			(0.042)
Male		–1.037	–1.204
		(0.850)	(0.848)
Male × Age		0.090	0.122
		(0.135)	(0.135)
Constant	0.163	0.581	–1.570
	(0.433)	(0.610)	(1.521)
N	65	65	65

S3.2 Logit regressions

Random effects model

Table S2: **Choice in first round in sender-receiver game: logit regression.** The variable Choice is 1 when the subject mistrusts as receiver, and lies as sender; zero otherwise. Only observations in which subjects played the game in the first role are considered. The n-Backward Score is normalized in the unit interval. Standard error in parenthesis.

	(1)	(2)	(3)	(4)
	b/se	b/se	b/se	b/se
Age in Years	2.216***	2.456**	75.720**	60.138**
	(0.497)	(0.940)	(145.912)	(123.228)
Age in Years, squared			0.736*	0.752*
			(0.120)	(0.127)
Male		0.166	0.008	0.010
		(0.469)	(0.028)	(0.034)
n-Backward score				0.483
				(0.991)
Male × Age		1.058	1.696	1.663
		(0.540)	(0.894)	(0.919)
Constant	0.021***	0.026*	0.000**	0.000**
	(0.027)	(0.050)	(0.000)	(0.000)
N	67	67	67	64

Table S3: **Choice in first round in sender-receiver game: logit random effects model, robust standard errors.** Observations in which subjects played the game in the first and the second role are included in the analysis. The variable Second Time is the indicator of the round in which the child played the game in the second role. The n-Backward Score is normalized in the unit interval. Standard error in parenthesis.

	(1)	(2)	(3)	(4)
	b/se	b/se	b/se	b/se
Second Time	0.667	0.671	59.241**	41.940*
	(0.274)	(0.271)	(120.241)	(81.585)
Age in Years		1.543***	2.496***	20.713***
		(0.244)	(0.827)	(24.100)
Age × Second Time			0.460**	0.495**
			(0.171)	(0.171)
Age in Years, squared				0.835**
				(0.076)
Constant	2.469**	0.175*	0.012**	0.000***
	(0.876)	(0.168)	(0.021)	(0.000)
N	134	134	134	134

Random and fixed effects model

In table S4 we test the robustness of the random effects model comparing it to the fixed effect model.

Table S4: **Choice in first round in sender-receiver game: logit fixed and random effects model. Odds ratios are reported.** Observations in which subjects played the game in the first and the second role are included in the analysis. The variable Second Time is the indicator of the round in which the child played the game in the second role. Fixed effects: first two columns. Random effects: last two columns. Standard error in parenthesis.

	(1)	(2)	(3)	(4)
	b/se	b/se	b/se	b/se
Second Time	0.667	32.572*	0.667	0.732
	(0.272)	(62.815)	(0.272)	(0.990)
Age × Second Time		0.537**		0.984
		(0.162)		(0.216)
Constant			2.469**	2.483**
			(0.870)	(0.902)
N	50	50	134	134

S3.3 Behavior in Later Rounds

Strategic Analysis of Later Rounds

The conjectured reasoning and behavior studied in this paper, and outlined explicitly in Section 1, focused primarily on the first round of play. A natural conjecture is that learning from experience over multiple rounds within the experiment parallels the development with age of a child's initial approach to the experiment in the first round. Specifically, we have posited that on the initial move, starting with naive play, as children age, they apply recursive thinking to best respond first to naive play, and then to the best response to naive play, and then to the best response to the best response to naive play, and so on. On subsequent moves, children are no longer constrained to base their beliefs and decisions only on their own reasoning about what the other player will do, but rather, may incorporate their observations about how the opponent has in fact played. Whereas on the first round, we conjecture that children best respond to their a priori beliefs about the other player's behavior, and that these beliefs incorporate more and more rounds of recursive thinking as children age, on subsequent rounds, we conjecture that children best respond to beliefs informed by the empirically observed behavior of the other player in previous rounds. Two hypotheses naturally suggest themselves:

Backward looking best responses Children assume that the other player will play in the subsequent round as she played in the previous round, and best respond to this belief.

Forward looking best responses Children assume that the other player will select her action via backward looking best response relative to the child's previous behavior, and children best respond to this belief.

We have in fact programmed the *experimenter* to use backward looking best responses. We refer to the second mode of reasoning and behavior as "forward looking" because it involves attributing backward looking behavior to the opponent and then looking one step ahead. It is a reasonable conjecture that as children age, they move from backward looking to forward looking behavior. This would be parallel to the evolution of the first round reasoning sequences posited in Section 1, because forward looking best responses require recursive thinking whereas backward looking best responses do not. Indeed, one might go a step further, and posit that as in the case of first moves, in subsequent moves, children move further along the path of recursive thinking and apply higher-order forward looking best responses, best responding to the conjectured first order forward looking best response of the other player. This process could in principle be iterated.

Behavior in Later Rounds: Stickers Game

In our design, the experimenter playing the opponent in the stickers game was instructed to choose 4 stickers in the first round, and then one sticker less than the number chosen by the child in the previous round (that is, the best response to the child's last move). Against this strategy the child's best response would be to alternate between 3 and 5, and in particular this would be better than employing the same strategy as the experimenter. The optimal symmetric collusive agreement between the two players in this game would be to alternate between 4 and 5 stickers. Of course it is not credible that the child thinks that he can establish a precise agreement to alternate with the experimenter starting from the first round. Randomizing the choice or trying to settle into some alternating pattern would be more plausible ways to achieve higher payoffs cooperatively from the child's perspective.

Figure S3 reports the mean number of stickers chosen by the child in the first round, in the first five rounds and in the last five rounds. The figure shows a general pattern for later rounds similar to that for the first round: the number of stickers declines with age, reaches a minimum at age 7 and then increases for the oldest children. Two points merit attention. First, children of all ages reduce the number of stickers, responding to an opponent who is systematically undercutting their choices. More interestingly, children of age 6.5 to 8, who chose the minimum in the first round, realize the opportunity presented by an opponent who is not systematically playing the minimum (as the opponent selects 4 stickers on the first round), and in later rounds play a number of stickers larger than 1.

The panel data analysis reported in table S5 shows that children take into account previous moves of the opponent/experimenter, and adjust upwards when the opponent plays higher numbers; in all models considered the adjustment is smaller than one-half of a sticker per sticker chosen by the experimenter, but positive and significant, indicating that a policy of reciprocating may be guiding choices.

Figure S4 and Table S6 show the effect on payoffs gathered by children over the game. As expected, *given the rule of best responding to the last move we assigned to the experimenter*, behavior corresponding to the dominance solution (choosing 1 sticker) gives the minimum payoff, which is the payoff for children age 6.5 to 8. The average payoff is higher for children above 8 than for those between 6.5 and 8, as unlike the 6.5-8 year old, the children above 8 do not play the minimum number of stickers on the first move; the increased winnings vindicates the farsighted rationality of the oldest children's behavior.

Figure S3: **Stickers Game: Mean over the first five and last five rounds.**

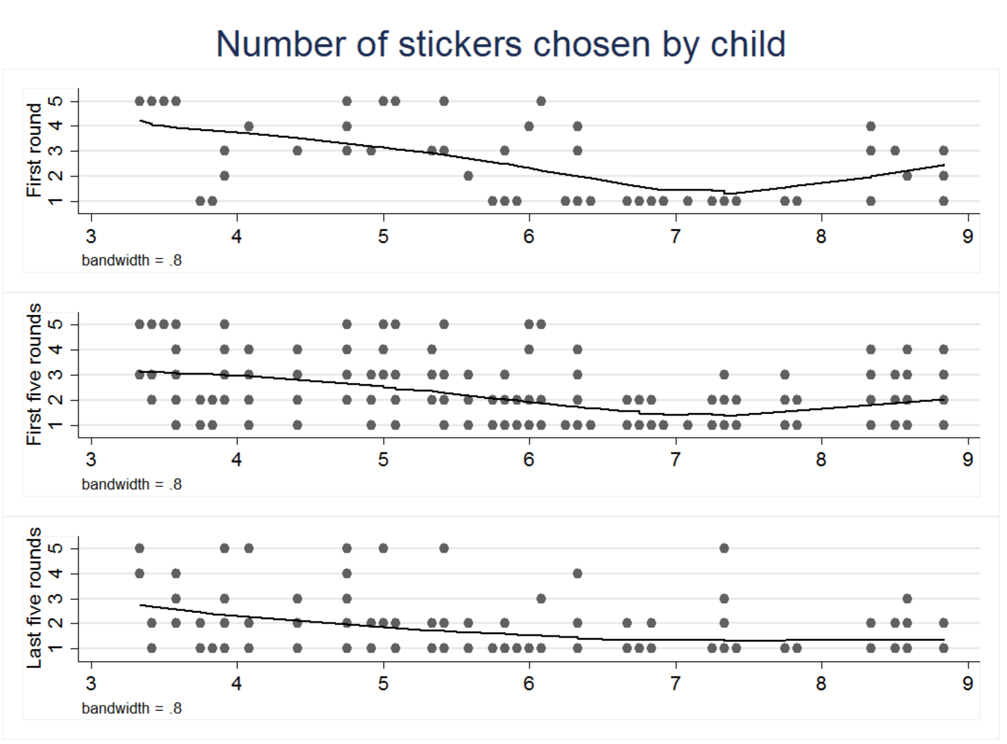


Table S5: **Number of stickers: panel regression, random effects.** Observations for all the rounds are included. The n-Backward Score is normalized in the unit interval. Standard error in parenthesis.

	(1)	(2)	(3)	(4)
	b/se	b/se	b/se	b/se
Exp. choice at t-1	0.366***	0.338***	0.791***	0.579***
	(0.036)	(0.042)	(0.125)	(0.143)
Exp. choice at t-1 $\times$ round		0.035***	–0.029	–0.003
		(0.009)	(0.020)	(0.023)
Exp. choice at t-2			–0.102	–0.177*
			(0.086)	(0.101)
Exp. choice at t-2 $\times$ round			0.059***	0.066***
			(0.016)	(0.019)
Age in Years				–0.767***
				(0.221)
Age in Years, squared				0.052***
				(0.017)
round				–0.127
				(0.098)
round $\times$ Age				0.007
				(0.012)
Constant	1.156***	0.911***	0.433***	3.714***
	(0.087)	(0.092)	(0.094)	(0.894)
N	509	509	442	442

Figure S4: **Stickers Game: Final Amount Won**

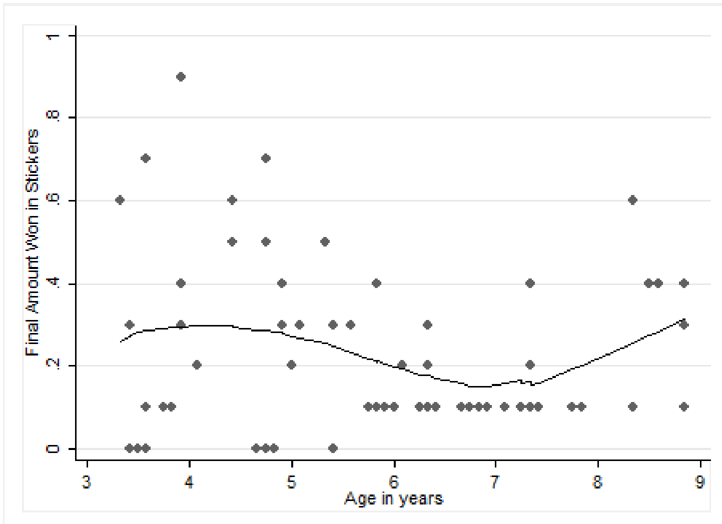


Table S6: **Stickers Game: Final Amount Won. OLS** The n-Backward Score is normalized in the unit interval. Standard error in parenthesis.

	(1) b/se	(2) b/se	(3) b/se	(4) b/se
Age in years	–0.020	–0.006	–0.221*	–0.228*
	(0.015)	(0.023)	(0.112)	(0.120)
Male		0.139	0.184	0.173
		(0.186)	(0.184)	(0.194)
Age in years, squared			0.018*	0.019**
			(0.009)	(0.010)
backward				
Male × Age		–0.024	–0.033	–0.032
		(0.030)	(0.030)	(0.031)
n-Backward Score				–0.143
				(0.116)
Constant	0.347***	0.270*	0.863**	0.955***
	(0.092)	(0.136)	(0.331)	(0.350)
N	69	69	69	65

Behavior in Later Rounds: Sender-Receiver Game

The experimenter facing the child in the sender-receiver game was instructed to play deceitfully and trusting in the first move (according to the role played) and then to play the best response to the child's previous move. The first moves were chosen to make mistrust and deceit respectfully a best reply for the child. Thus a child whose reasoning fell into step 2 of our sender-receiver reasoning sequence (see Section 1)–those who were deceitful as sender and mistrusting as receiver– would have won in either role on the first move. The experimenter's rule of best responding to the last move in the sender-receiver game matches the programmed behavior in the stickers game. Figure S5 displays the lowess estimates for the index of Deception (a variable equal to 1 when the child as sender indicates the empty box) and Mistrust (a variable equal to 1 when the child as receiver chooses the box not indicated by the experimenter) over all rounds of the game. In both cases, the average play over age converges to approximately 50 %, as in the mixed strategy equilibrium. Tables S7 and S8 show the panel data analysis for the sender and receiver, and how they respond to past histories. Children in both roles respond to the choice of the opponent in the previous two trials, responding with the best response to the move of the experimenter two trials earlier (see column (4) of tables S7 and S8).

Tables S7 and S8 include observations in which subjects played the game for the fist and second time. In tables tables S9 and S10 we focus the analysis on the first time only.

Over the rounds, the fraction of deceptive/mistrustful moves converges to half, both when the child played the game the first and when he played it the second time. The panel data regression of the deception/mistrust index over the rounds has a constant of 0.64 and a coefficient for round equal to -0.036 (p-value = 0.011) when we consider the observations in which the child played for the first time; see Table S11. For games where the child played the second time, the constant is 0.61 and a coefficient for round equal to -0.028 (p-value = 0.055); see Table S12.

Age and the n-backward score has the expected effect. Age increases the deceitful behavior when the child plays as sender. The n-backward score is associated with more mistrustful behavior when the child plays as receiver.

Overall, children with higher age earn more, as Table S13 shows.

Figure S5: **Deception as Sender, Mistrust as Receiver: Mean over the entire session.** Both first and second role observations are used. The first two panels display the lowess estimate, separately, for children playing as Senders and Receivers. The last panel reports the estimate for the mean over the two games, in the two roles, of Deception and Mistrust.

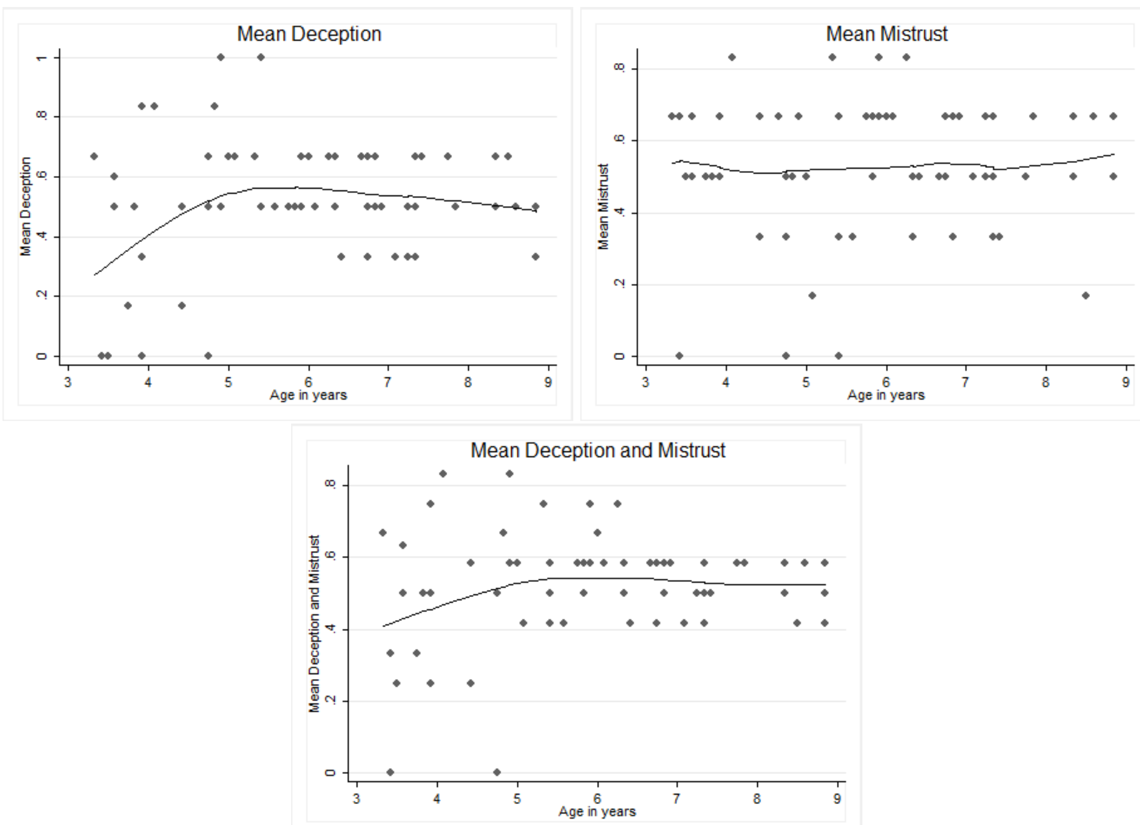


Table S7: **Current Choice as sender and past choices: OLS** Observations in which subjects played the game both for the first and second time are included. The n-Backward Score is normalized in the unit interval. Standard error in parenthesis.

	(1)	(2)	(3)	(4)
	b/se	b/se	b/se	b/se
Exp's move at t-1	–0.062	–0.035	0.358*	0.690***
	(0.055)	(0.061)	(0.188)	(0.254)
Exp's move at t-2		–0.082	–0.103*	–0.184***
		(0.062)	(0.062)	(0.064)
Exp's move at t-1 × Age			–0.064**	–0.130***
			(0.029)	(0.040)
Age in years				0.436***
				(0.164)
Age in years, squared				–0.028**
				(0.013)
n-Backward score				–0.202
				(0.180)
Constant	0.505***	0.515***	0.524***	–0.799*
	(0.036)	(0.052)	(0.052)	(0.472)
N	334	267	267	255

Table S8: **Current Choice as receiver and past choices: OLS** Observations in which subjects played the game both for the first and second time are included. The n-Backward Score is normalized in the unit interval. Standard error in parenthesis.

	(1)	(2)	(3)	(4)
	b/se	b/se	b/se	b/se
Exp's move at t-1	–0.070	–0.049	0.046	0.289
	(0.055)	(0.062)	(0.179)	(0.252)
Exp's move at t-2		0.173***	0.167***	0.119*
		(0.062)	(0.063)	(0.065)
Exp's move at t-1 × Age			–0.016	–0.058
			(0.028)	(0.040)
Age in years				–0.176
				(0.161)
Age in years, squared				0.015
				(0.012)
n-Backward score				0.481***
				(0.179)
Constant	0.552***	0.438***	0.442***	0.662
	(0.042)	(0.058)	(0.058)	(0.479)
N	334	267	267	255

Table S9: **Current Choice as sender and past choices: OLS.** Only observations in which subjects played the game for the first time are included. The n-Backward Score is normalized in the unit interval. Standard error in parenthesis.

	(1)	(2)	(3)	(4)
	b/se	b/se	b/se	b/se
Exp's move at t-1	0.016	0.064	0.547*	1.090***
	(0.081)	(0.090)	(0.300)	(0.411)
Exp's move at t-2		–0.066	–0.091	–0.210**
		(0.091)	(0.092)	(0.095)
Exp's move at t-1 × Age			–0.075*	–0.177***
			(0.045)	(0.063)
Age in years				0.412
				(0.267)
Age in years, squared				–0.023
				(0.020)
n-Backward score				–0.173
				(0.312)
Constant	0.438***	0.420***	0.430***	–0.933
	(0.053)	(0.073)	(0.073)	(0.764)
N	155	124	124	116

Table S10: **Current Choice as receiver and past choices: OLS** Only observations in which subjects played the game for the first time are included. The n-Backward Score is normalized in the unit interval. Standard error in parenthesis.

	(1)	(2)	(3)	(4)
	b/se	b/se	b/se	b/se
Exp's move at t-1	–0.080	–0.002	0.309	0.620*
	(0.075)	(0.086)	(0.258)	(0.332)
Exp's move at t-2		0.195**	0.167*	0.141
		(0.086)	(0.089)	(0.089)
Exp's move at t-1 × Age			–0.053	–0.105*
			(0.042)	(0.055)
Age in years				–0.183
				(0.211)
Age in years, squared				0.013
				(0.017)
n-Backward score				0.691***
				(0.218)
Constant	0.570***	0.439***	0.458***	0.611
	(0.056)	(0.080)	(0.081)	(0.608)
N	179	143	143	139

Table S11: **Deception and mistrust index over the rounds. OLS** Only observations in which subjects played the game for the first time are included. The n-Backward Score is normalized in the unit interval. Standard error in parenthesis.

	(1)	(2)	(3)
	b/se	b/se	b/se
Round	–0.037**	–0.037**	–0.040***
	(0.014)	(0.014)	(0.015)
Age in years		0.209*	–0.000
		(0.120)	(0.131)
Age in years, squared		–0.015	–0.001
		(0.010)	(0.010)
n-Backward score			0.320**
			(0.147)
Constant	0.647***	–0.035	0.532
	(0.057)	(0.354)	(0.379)
N	401	401	383

Table S12: **Deception and mistrust index over the rounds. OLS** Only observations in which subjects played the game for the first time are included. The n-Backward Score is normalized in the unit interval. Standard error in parenthesis.

	(1)	(2)	(3)
	b/se	b/se	b/se
Round	–0.028*	–0.028*	–0.026*
	(0.015)	(0.015)	(0.015)
Age in years		0.146	0.220*
		(0.119)	(0.132)
Age in years, squared		–0.012	–0.016
		(0.010)	(0.010)
n-Backward score			–0.140
			(0.149)
Constant	0.617***	0.199	–0.006
	(0.057)	(0.350)	(0.383)
N	401	401	383

Table S13: **Sender and Receiver Game: Final Amount Won. OLS** The n-Backward Score is normalized in the unit interval. Standard error in parenthesis.

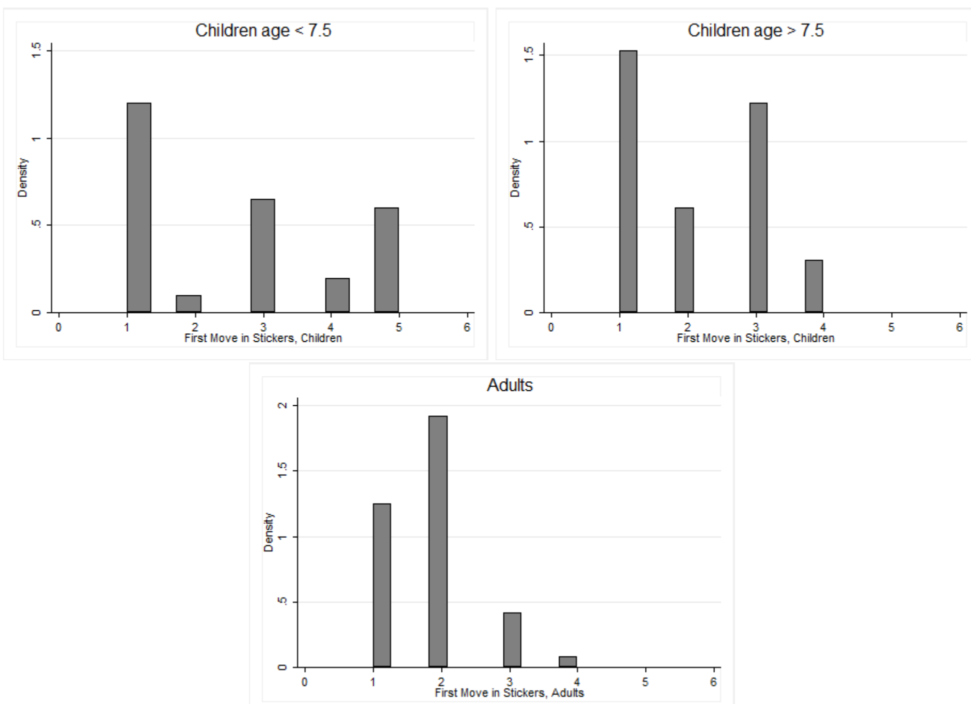
	(1)	(2)	(3)	(4)
	b/se	b/se	b/se	b/se
Age in years	0.474***	0.586***	1.158	0.764
	(0.102)	(0.156)	(0.795)	(0.867)
Male		1.083	0.964	1.533
		(1.290)	(1.305)	(1.399)
Age in years, squared			–0.048	–0.019
			(0.066)	(0.069)
Male $\times$ Age		–0.196	–0.173	–0.248
		(0.209)	(0.212)	(0.221)
n-Backward Score				–0.054
				(0.838)
Constant	0.074	–0.538	–2.112	–0.821
	(0.635)	(0.943)	(2.346)	(2.527)
N	69	69	69	65

S3.4 Comparison with Adult Behavior

Table S14: **Sender Receiver Game, Adults Move: Logit panel data.** The n-Backward Score is normalized in the unit interval. Standard error in parenthesis.

	(1)	(2)	(3)	(4)
	b/se	b/se	b/se	b/se
Round	–0.001	–0.001	–0.013	–0.013
	(0.026)	(0.026)	(0.112)	(0.112)
Round squared			0.001	0.001
			(0.008)	(0.008)
n-Backward Score		0.550		0.550
		(0.546)		(0.546)
Constant	–0.322*	–0.553*	–0.293	–0.524
	(0.188)	(0.296)	(0.315)	(0.390)
N	528	528	528	528

Figure S6: **Stickers Game: First move for children and adults**



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