

Behavioral transition with age in social dilemmas: from reciprocal youth to persistent response in adulthood

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While human societies are extraordinarily cooperative in comparison with other social species, the question of why we cooperate with unrelated individuals remains open. Here, we report results of a lab-in-the-field experiment with people of different ages in a social dilemma. We find that the average level of cooperation is age-independent except for the elderly, and a behavioral transition towards the end of adolescence. Although all ages react to the cooperation received in the previous round, young teenagers mostly respond to what they see in their

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neighborhood regardless of their previous actions. Decisions then become more predictable through midlife, when the act of cooperating or not is more likely to be repeated. Our results show that mechanisms such as reciprocity, which is based on reacting to previous actions, may promote cooperation in general, but its influence can be hindered by the fluctuating behavior in the case of children.

The underlying conflict between one's own benefit and helping others poses an evolutionary conundrum¹ and lies at the heart of many social dilemmas². In particular, human societies are extraordinarily cooperative in comparison with other social species³⁻⁶. The study of this problem has been addressed in a stylized but insightful manner using the Prisoner's Dilemma^{7,8}, arguably the most difficult context for the emergence of cooperation: individuals are tempted to defect because of greed (the reward for cheating against a cooperator is the largest payoff in the game) and of fear (players cheated upon receive the lowest possible payoff), while mutual cooperation is the most beneficial outcome in a collective sense. From a theoretical perspective, several mechanisms have been proposed to explain how cooperation can arise in such a context^{9,10}. Prominent among those are kin selection^{11,12}, reciprocity^{7,13}, reputation¹⁴ and different forms of assortment¹⁵, including the greenbeard effect¹⁶ and the existence of a structure in the population¹⁷. Most of these mechanisms have a wide range of applicability where they successfully allow to understand cooperative behavior. Therefore, although there is no general theory of cooperation, significant and promising progress has certainly been made.

From the experimental part, although much work has been done up to date¹⁸, many important

issues are yet unresolved or even unexplored. In particular, whether or not humans' propensity towards cooperation changes through the life cycle is a yet-to-answer challenge. This is the focus of our study. Indeed, a vast majority of experiments conducted up to now involve volunteers coming from Economics, Psychology or other academic disciplines, i.e., with a high educational level and typically in the 18–25 years old range (for examples on work with different types of subjects, see, e.g., Refs. 19 and 20). On the other hand, although there are many studies examining altruistic behavior in children^{21–23}, very little is known about how cooperative behavior changes across generations. Indeed, to the best of our knowledge, there is only one earlier study in which subjects of different ages were involved in the same experimental setup to test their cooperativeness, namely the work by Charness and Villeval²⁴. They conducted experiments with employees of two French firms using junior (under 30) and senior (over 50) subjects, and on a conventional laboratory setup with students and retirees. Their main finding is that seniors were more cooperative than juniors, along with some other characteristics that imply that keeping seniors in the work force may be beneficial. We will come back to this work, very related to ours on the old age range, in the discussion. A few other works have investigated the possible decline of decision making abilities of older individuals as well as the relation of other social interaction contexts, such as trust, and age (see, e.g., Ref. ²⁴ for references). Among the latter, the paper by Sutter and Kocher²⁵ will also be relevant for our discussion below.

Here we address the issue of possible age dependences of the experimentally observed behaviors by conducting a lab-in-the-field experiment, in which volunteers of different ages play n -player Prisoner's Dilemmas (PD). As it has been recently shown that n -player PD lead to the

same qualitative results when $n \geq 3$ ²⁶, we focused in the case of the $n = 4$ game (more information is provided in *Methods* and in the Supplementary Information (*SI*)). In a first stage, we run an experiment during the 1st Board Games Fair (DAU Barcelona Festival, <http://daubarcelona.bcn.cat>) in December 2012 (hereafter referred to as DAU experiment). Participants with ages between 10 and 87 among visitors of the Festival were randomly recruited to play an iterated 4-person PD for 25 rounds (this number was fixed, but unknown to the participants). In order to compare the behavior of subjects of different ages, we either placed them in a group with other players of similar age (we divided the age range as follows: 10–16, 17–25 –which corresponds to the typical age range in this sort of experiments–, 26–35, 36–45, 46–55, 56–65, and 66 and over) or in a group with other participants irrespective of their age (control groups). Table 1 summarizes the main features of these groups. It is worth stressing that the Festival was more an exhibition and a social event than a convention aimed at attracting well-trained players. Moreover, volunteers that participated in the experiment did not know each other and did not show up by themselves, but we had to recruit them, somewhat diminishing the possibility of self-selection. As it is shown below, the youngest group showed a significantly distinct behavior with respect to the rest of the groups. Therefore, in order to reproduce the results found for the children, we subsequently carried out a sequel with the same experimental setup at the Jesuïtes Casp (Casp Jesuits School, <http://www.casp.fje.edu>, hereafter referred to as School experiment), focusing on reproducing the results of the young teenager group with 53 new subjects between 11 and 12 years old. See *Methods* below for a detailed description of the volunteer profile and recruitment at the DAU and School experiments and the experimental procedure. Full details on the software and the experiment instructions are included in the *SI*.

Results

We begin the report on our results with the DAU experiment. The overall fraction of cooperative actions c in each round, averaged over all players (and, therefore, over all age groups) quickly drops from initial values around 0.65 to values around 0.45 (see *Fig. S7* in *SI*). This behavior is consistent with previous findings in experiments with humans playing a Prisoner's Dilemma²⁶. Filled circles in *Fig. 1* show the probability of cooperation –i.e., average fraction of cooperative actions– over the last 15 rounds for the 7 groups considered (results averaging over all rounds are qualitatively similar, cf. *Fig. S8* in *SI*). Additionally, the horizontal line represents the observed value for the control group. It is apparent that the level of cooperation in groups from 17 to 65 years old and the control is quite similar, showing values in the range of $0.4 < c < 0.47$. In contrast, the stationary level of cooperation, $c = 0.34$, observed in the first group –under 17 years old–, is significantly (p -value $< 10^{-4}$) lower than the control group, whereas the cooperation of the last group – over 65 years old– is significantly higher $c = 0.55$ (p -value $< 10^{-4}$). It thus follows that, in the DAU experiment, extreme age groups showed a behavior clearly distinct from the mid-aged groups: while children between 10 and 17 years old were quite uncooperative, the elderly adopted a very cooperative behavior (see *Table S1* in the *SI* for a null-hypothesis binomial test).

The observed behavior for the young teenagers group, impressive as it may look, must be carefully considered. There are a number of reasons why the cooperation level may be lower in this group, but prominent among those is that the people attending the DAU Festival, although it is a board games exhibition rather than a competition, may be more competitive than the average

individual. The results for the control group and for the age groups from 17 through 65 years old are consistent with those reported in similar experiments²⁷⁻³¹, abundant in particular for the 17-25 group. Most adult participants in the Festival were board game players themselves, so this agreement might rule out the effects of volunteer competitiveness and, in fact, it gives even more relevance to the cooperative level of the elderly players, which we will analyze later on. However, the lack of reference values for the 10-16 group, and the small number of participants we had, prompted us to replicate the experiment for this age segment, which we did with the School experiment. The results for the average cooperation level in the School experiment are also shown in Fig. 1 (filled triangles), and clearly indicate that the level of cooperation in the young teenager group is not statistically different from the control or the other groups, neither for the participants in the School experiment, nor for all participants at DAU and School pooled together (filled squares). Therefore, it can be safely concluded that the average cooperation level is the same in all the age ranges from 10 through 65 years old. As we shall discuss later on, we believe that the observed differences between both sets of children arise from their very same behavior in front of the dilemma, although we also acknowledge that they could be rooted in the apparent higher competitiveness of the DAU children.

However, observing no significant differences in the fraction of cooperative actions among children and mid-aged individuals does not imply that all players, regardless of their ages, play following the same behavioral rules. It might well be the case that the strategies followed give rise to the same average level of cooperation, despite them being distinct. To shed more light on how people of different ages behave in social dilemmas, we analyzed how the actions changed in

relation to participants' own choice in the previous round and the cooperation level they observed in their neighborhood. This analysis has proved to be insightful in recent experiments^{26,29,30}, in which it unveiled an unexpected dependence of the players' actions on their own previous decision, something that had not been pointed out before. In addition to this behavior, termed moody in the above referenced papers, conditional cooperation, i.e., a dependence of the probability of cooperation on the number of partners that cooperated in the previous round was also observed. The specifics of this dependence may vary from one experiment to another: while there is often a monotonously increasing trend (approximately linear) of the probability to cooperate vs the number of cooperative neighbors of the focal player in the previous round, it is also common to find less clear dependencies.

Results from such analysis for our experiment are shown in Fig. 2 for the control and the children groups (DAU and School). It is immediately apparent from the plot that control players clearly reproduce the moody pattern, namely, the dependence of the current decision on the previous action, while reacting to the context in a not well defined manner. This is also the case for all age groups except young teenagers, see Fig. S9 in the *SI*. Remarkably, the latter group did not show any evidence of dependence on their actions on their own previous one, although they did keep their behavior conditioned to the actions they observe, i.e., they reciprocate as all other age groups. The only exception to this behavior comes when no partner cooperated, and in this situation our findings indicate that young teenagers tend to use an alternating strategy between the two actions.

Further evidence of the previous behavior is provided in Fig. 3, where we show the measured conditional transition rates that a player cooperates following a cooperative action, $p(C|C)$ or after defecting, $p(C|D)$. These two quantities are markedly different for all groups except for the children –note that irrespective of them being from the DAU or the School experiments results are roughly the same–, an observation that confirms our previous statements regarding the noticeable behavioral differences between the youths and the rest of players. We observe, first, that the behavior of the participants aged above 17 is statistically indistinguishable from that of the control group, and, second, that the probability to cooperate following a cooperation is more than twice that following a defection. This substantial difference between the two conditional probabilities is completely absent in the case of children: they have the largest transition rate to defection after they have cooperated and the smaller permanence probability as cooperators if they did so in the previous round. Indeed, computing the average number of rounds that an individual plays as a cooperator or as a defector sequentially, one finds that children have the shortest cooperative chain, see Table 1. Again, this happens in the two sets of players analyzed, which suggests that the observed difference in the average cooperation level of the two groups of children (noticeable in Fig. 1) should arise from the initial fraction of cooperators in the first rounds – as teenagers mostly reciprocate what they observe in their neighborhood in spite of their previous action, differences in the level of cooperation at the very first stages will propagate in a sort of feedback till the last round.

Altogether, the previous result for the youth indicates that children are inconstant in their decisions, as they are almost equally likely to repeat the last action and to change it, with defection

being slightly more probable. Interestingly, this implies that children behave in a manner that may lead to cooperation breakdown or at least to its decrease, as they are not reliable partners and they may in consequence assume that their partners are not reliable as well, thus making it impossible to establish a stable cooperative scenario that ultimately could sustain long-term cooperation. Furthermore, the results in Fig. 2 and Fig. 3 together discard the possibility that children play randomly. If this were the case, they would play the same way whatever the level of cooperation in their neighborhood were, but Fig. 2 shows that they are influenced by what they observe, hence, the larger the number of cooperators in their group is, the larger the probability of playing as cooperators is.

The conditional transition rates also provide hints on the larger cooperativeness of the elderly. Albeit not statistically significant, the results in Fig. 3 suggest that in this group the probabilities to cooperate may be the largest in all groups. In particular, the fact that $p(C|C)$ is very large leads to very long sequences playing as cooperators. Indeed, as seen in Table 1, the elderly show the largest cooperative chain of all groups, more than two times the average length of the C sequences in children. In turn, the estimated conditional probabilities can be used to inform a Markov chain model that predicts the probability of permanence of a given action for at least n rounds. Such a model fits accurately the experimental observations, as seen in Fig. S5 in the SI. Furthermore, we can also estimate the total probability of cooperation: using Bayes' theorem one has that $p(D|C)p(C) = p(C|D)p(D)$, which, taking into account the normalization condition $p(D) = 1 - p(C)$, yields for the probability of cooperation

$$p(C) = \frac{p(C|D)}{p(D|C) + p(C|D)}.$$

Fig. S4 compares the prediction to the observed result, showing again a very good agreement (see also the null-hypothesis test shown in Table S2 of the *SI*). This Markov chain model allows us to draw another, most relevant conclusion: one-step memory is enough to explain the actions of the players in n -player PD (in agreement with the statistical analysis presented in ²⁶). The model has also allowed to compute the profit's distribution, see Fig S6 and Table S3 in the *SI*.

Discussion

The findings of this study represent an important step towards a more comprehensive understanding of cooperation in humans. In particular, our experiment has a number of important implications regarding the evolution of cooperation from childhood to the elderly. The most relevant findings concern the clear differences found between children and the rest of groups and the high cooperation showed by the elderly. As for the teenagers, the observed distinct behavior might be due to the unsophisticated development of social values in children ²¹ with respect to adult subjects ³². Admittedly, children have not fully developed cognitive and strategic abilities related to social and moral implications, such as ethics, morality, collective fairness, and cooperation. They are at a stage in which they realize that rules are not rigid and are formed by mutual consent for reasons of fairness and equity and hence that these rules can be changed as the need arises. Therefore, when they meet their peers, they adopt a strategy that essentially looks for a kind of social equality, mostly reciprocating the behavior they observe. In other words, they are not intrinsically cooperators nor defectors and implement those strategies that they believe will allow them to benefit more in return or based on the principle of what is good for others is also good for me. Interestingly, as

shown in Fig. S6 and Table S3 in the *SI*, their behavior backfires, they earn less than the other age groups, and their profit distribution is much less scattered. Conversely, mid-aged individuals and the elderly base their decisions on what people around them do and use simple heuristics, reacting to the context of cooperation they observe and attempting to keep their previous action to some extent, to decide whether or not to cooperate. Given the relevance of our results, we however discuss in the *SI* other possible effects influencing our results.

Ultimately, our work aligns with previous claims about the existence of a developmental transition in humans over time regarding empathy³³ and quantitatively shows that the same shift takes place when humans are faced to social dilemmas, with a strategic change from a response to others' actions to a more sophisticated moody (also prosocial) conditional behavior. This finding, obtained by having subjects in a very wide range of ages participating in the same experiment, adds to observations of how altruistic or reciprocal behavior develops in early childhood^{22,23}. It thus seems possible that, as cooperative behavior increases with age below 10 years, most likely due to the development of a theory of mind, the same theory of mind might give rise to a period in life in which children's behavior is characterized by their flexibility and ability to compromise and change rules as required. This hypothesis could also be related to the transition in trust and trustworthiness observed by Sutton and Kocher²⁵ (see also Ref. 34) and to the observed behavior of children 6 to 12 year old in public good and dictator experiments³⁵, very different from that of older children and adults as they increase in later rounds of the experiment. The decrease in spitefulness in the same age range³⁶ and the increasing inequality acceptance³⁷ are further hints about such a key developmental transition.

Moreover, our results imply that mechanisms such as reputation and reciprocity, that are based on social perception, might be universal for humans, i.e., they are not relative to the age of the individuals. However, their impact in the long-term stability of cooperation might be hindered by the inconstant behavior in the case of children. At the same time, the large age range in which individuals exhibit similar behavior allows to generalize observations with the usual experimental subjects: Thus, recent experiments showing that population structure do not support human cooperation in PD^{29,30} should indeed be reproducible with subjects aged 17 through 65. The inconstant behavior of young teenagers would also lead to lack of cooperation in a network setting, albeit for different reasons.

Our results on the two age groups that behave differently have several policy implications. First, they suggest that, on the side of teenagers, specific strategies should be developed to promote a transition to a more persistent prosocial behavior and to help them understand the need for some perseverance. Secondly, the susceptibility of children's behavior to what they see in their environment regardless of their own previous choices, points to the fact that their future moral and strategic thinking could be conditioned to the education they have received. Finally, as suggested previously, fostering the participation of older individuals in key social decisions or collective negotiations³² and keeping them longer in the workforce²⁴ may be judicious procedures.

Methods

Experiment at DAU The experiment was carried out with 168 volunteers selected from the attendees to DAU Barcelona Festival 2012 (1st Board Game Fair of Barcelona, December 15 and 16). During the recruitment process, the experiment was referred to as a *social experiment* and nobody knew in advance what the experiment was about. Following the call for participation, we selected the 168 volunteers regarding age distribution criteria, with 82 males and 86 females representing the 48.81% and 51.19% of the total number of players, respectively. In order to satisfy ethical procedures, all personal data about the participants were anonymized and treated as confidential.

For every age range, and for the control treatment in which people played together irrespectively of their ages, there were 6 groups, except for the 17–25 range (5 groups), the 56–64 range (3 groups) and the over 66 range (4 groups). Specifically, the volunteers' set was divided into 42 subsets of 4 players according to the age distribution shown in Table 1. Control subsets constitute samples with an heterogeneous distribution of ages. Each subset of 4 volunteers made up a game, that is, every player had partners of his own age range (except in the control subsets) playing everyone against everyone.

All the volunteers played via a web interface specifically created for the experiment (see below) that was accessible through the computers available in the room. At least three researchers supervised the experiment in the room (which had a maximum capacity of 12 players), preventing any interaction among the volunteers. They were not allowed to talk or signal in any way. To further guarantee that potential interactions among players seating next to each other in the room

do not influence the results of the experiment, the assignment of players to the different computers of the room was completely random. Hence, physical neighbors do not necessarily correspond with game mates. In addition, as described below, the colors used to code the two available actions of the game were also selected randomly, further decreasing the likelihood that neighboring participants could influence each other.

Volunteers played a 2×2 PD game with each of their 3 neighbors, choosing the same action, either to cooperate (C) or to defect (D), for all opponents. The experiment was conducted using a slightly modified version of a software that was previously used in another, though larger, experiment³⁰. Volunteers were allowed to choose language between Spanish or Catalan. Upon accessing the software, participants entered the directions for the experiment (detailed information is provided in the *SI*, including snapshots of the interface in Figs. S1–S3). When every participant of the group finished reading, the experiment began, lasting for 25 rounds (participants were not aware of the number of rounds). After completing the experiment, participants were asked to fill a short questionnaire and then proceeded to a separate part of the room where they received their payments. Volunteers under the legal age played the game by themselves while their guardians waited outside the room, and received their payment with the approval and surveillance of their guardians. The overall average payment was 15.12 euros including a 5 euros show-up fee. Total earnings in the experiment ranged from 3.80 to 27.95 euros.

Experiment at Jesuïtes Jesuïtes Casp is located in the city center of Barcelona. Jesuïtes is part of a school network of seven semi-private centers, most of them located in neighborhoods of the

city of Barcelona. Jesuites Casp students have a very diverse profile, it is a large school with about 1200 students from 6 years old up to 18 years old. Each grade has 5 class groups.

The experimental setup followed the same rules as in the case of the experiment at DAU. The same web interface was used and an identical game was played. The experiment was performed on March 4, 2014. However, volunteers participated in a different way. Based on the DAU results, we decided to focus on a large group of teenagers between 11 and 12 years old. Young teenagers were from first year of ESO (Compulsory Secondary School) and from two different class groups (ESO 1-A and ESO 1-E). The teenagers only knew in advance that they were going to participate in a scientific experiment during one hour class but they were not aware of any detail about the specifics of the experiment. The students' parents were informed of the participation of their children in the experiment and explicitly authorized it. This hour class typically divides each group, of 26 and 27 pupils, into two different subgroups these two classes; in this way, we had groups of 14 and 13 teenagers in 4 different rooms and split in a random way. Note that, as we played a four people game, one student did not fit in any group, and was set to play against computer robots without informing him in order to avoid leaving any of them out, but the corresponding data have been ignored in the analysis. They did not know who their partners were, and we made sure that each player in each game was placed in a different room. In each room, one member of the research team and one teacher supervised the evolution of the experiment. The experiment was carried out with 27 males and 26 females representing 51% and 49% of the total number of volunteers. The average profit for each participant was 14.89 euros. Total earnings ranged from 9.25 euros to 19.45 euros and volunteers were informed about their own profit right after finishing the experiment.

Payments were issued in the form of checks valid at a bookstore which also sells school materials and educational toys located at 5 minutes walking distance from Jesuites Casp. The checks were delivered to volunteers by the school teachers a couple of weeks after the experiment when parent's signatures in checks receipt were collected.

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Supplementary Information is linked to the online version of the paper at www.nature.com/nature.

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age group	1	2	3	4	5	6	7	control	School
average age (years)	12.33	21.10	30.25	39.96	49.54	60.00	72.56	36.75	12.17
minimum age (years)	10	17	27	36	46	56	66	13	12
maximum age (years)	16	27	35	45	55	65	87	57	13
number of volunteers	24	16	20	24	24	12	20	24	52
number of games	6	4	5	6	6	3	5	6	13
rounds playing as C	1.50	2.36	3.11	2.15	2.92	2.80	3.68	2.92	1.72
rounds playing as D	2.51	2.62	3.55	2.81	2.72	3.20	2.75	3.24	2.02

Table 1: **Age groups.** The players pool was classified into 9 different groups according to the age of the participants, including two for the children (one in the DAU experiment and another in the School experiment) and a control group. Each of these groups were in turn divided into subsets of 4 subjects that played among them. Note that the last two entries of the Table refer to the average number of rounds a given strategy was played sequentially, i.e., the average length of a C or D chain. See the text for further details.

Figure 1 Cooperation by age group. Fraction c of cooperative actions averaged over the last 15 rounds as a function of the average age of each group. Filled circles correspond to the DAU experiment, the filled triangle to the School experiment and the filled square stand for the average value when all children are considered. The horizontal dashed line shows the value for the control group. X-axis bars cover the age range of the groups divided as follows: 10–16, 17–25, 26–35, 36–45, 46–55, 56–65, and over 66. Y-axis error bars represent the standard deviation of a binomial distribution over the size of the age group and the number of rounds analyzed (15). See the *SI* for a discussion on the error bars which applies to all Figures. Error bars correspond to one standard deviation.

Figure 2 Behavior dependence on the cooperation context in the previous round. Empirical probabilities of cooperating after playing C or D , conditioned to the context (number of cooperators in the previous round) for the control sample (left) and for all children in DAU and School experiments pooled together (right), computed over all the rounds (25) of the experiment. Children show a different behavior as compared to the rest of the groups, namely, their decisions to cooperate or defect do not seem to depend on their own actions in the previous round. The error bars represent the standard deviation of a binomial distribution. See also Fig. S9 for the same analysis particularized for each age group.

Figure 3 Children exhibit the same cooperation probability following a cooperative or a defective act. Experimentally measured probability to cooperate following a cooperation $p(C|C)$ (filled squares) or a defection $p(C|D)$ (filled circles) for each age group computed over all the

rounds (25) of the experiment. For the young teenager group, the filled symbols correspond to the DAU experiment, and the empty symbols to the School experiment. The error bars represent the standard deviation of each probability over the different age groups.





