

## **Far but finite horizons promote cooperation in the Centipede game**

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### **Abstract**

The sequential Centipede game models repeated reciprocal interaction, in which two players alternate in choosing between cooperation and defection. In an attempt to increase the game's applicability to real-life decision contexts, we investigated the effects of game length and termination rules on cooperation in the Centipede game. We found that increasing the game length from 8 to 20 decision nodes increased cooperation, but only if the game's end was known to participants. Games with unknown ends manifested lower cooperation levels without an endgame effect (increased defection immediately before a known end). Random game termination by the computer appeared to increase the percentage of games adhering to the Nash equilibrium outcome mandated by game theory, and generally lowered cooperation levels.

**Keywords:** Centipede game; Backward induction; Endgame effect; Cooperation; Reciprocity

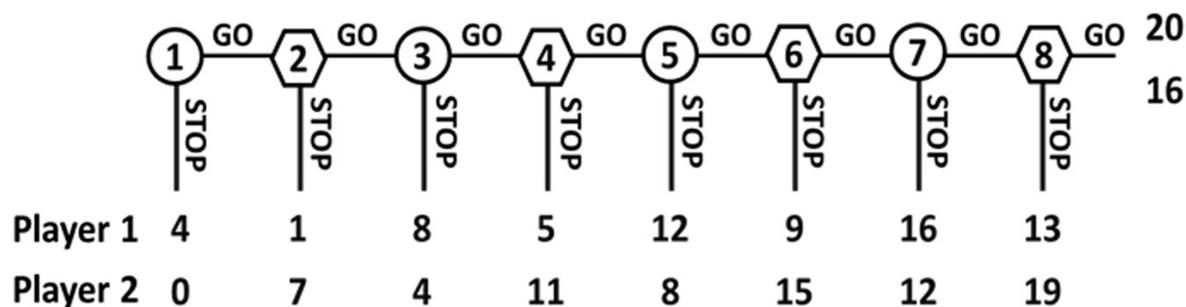
*PsycINFO classification:* 2340, 3020

*JEL Classification:* C72, C92, D03, D74

## **1. Introduction**

Many human relationships are characterized by repeated interactions based on a reciprocal pattern of give-and-take. A familiar form is seen in dyadic relationships in which people take turns either cooperating by helping each other or defecting from the sequence of reciprocally helpful actions. In such situations, the benefit ( $b$ ) of a cooperative action to the recipient is generally as great or greater than the cost ( $c$ ) of the action to the cooperator, hence  $c \leq b$ . Typical examples of this pattern include neighbors taking turns looking after each other's pets while the other family is away, at a small cost in time and effort but large benefit to the recipients, and university researchers taking turns reading each other's manuscripts or grant applications before submission, again at relatively small cost to the cooperator but potentially large benefit to the recipient.

Against this background, Rosenthal's (1981) Centipede game, a standard version of which is displayed in Fig. 1, can provide a helpful model. The original form of this sequential game includes two players with *complete information* (full knowledge of the game and the payoffs to both players) and *perfect information* (knowledge of all previous moves at every stage of the game) who take turns in deciding between two possible moves: a cooperative GO move that allows the game to continue, and a noncooperative or defecting STOP move that terminates the game immediately with a relatively favorable payoff to the defector.



**Fig. 1** Linearly increasing Centipede game.

In Fig. 1, the numbered decision nodes are enclosed in circles for Player 1 and hexagons for Player 2. Player 1 begins at the left, choosing whether to GO (cooperate) or to STOP (defect), a STOP move terminating the game immediately with payoffs of 4 to Player 1 and 0 to Player 2 as shown in the terminal nodes at the bottom of the figure. A GO move hands the next move to Player 2, who can choose to STOP the game, with payoffs of 1 to Player 1 and 7 to Player 2, or can choose GO and hand Move 3 to Player 1, and so on. The numbers represent utilities reflecting the players' true preferences, but it is convenient to think of them as monetary units (in any denomination). If neither player chooses to defect (STOP) at any of the eight numbered decision nodes, then the game comes to its natural end, with payoffs of 20 to Player 1 and 16 to Player 2, shown on the right of Fig. 1. In general, if both players cooperate repeatedly, then the payoffs mount up, but for each individual move, corresponding to a cooperative action, the cost to the cooperator in this example is  $c = 3$  and the benefit to the recipient is  $b = 7$ , and these cost and benefit values remain fixed throughout the game. Hence, in this particular Centipede game, a cooperative move always decreases a player's payoff by three units and increases the co-player's payoff by seven units.

The example game is a linear Centipede version because the joint payoffs of the player pair increase linearly from one terminal node to the next—by four units in this case. Exponential Centipede games and other versions have also been examined and used in experiments. In all its versions, the strategic structure of the Centipede game is generally considered to be highly paradoxical, because the game-theoretic solution—the way the game would be played by ideally rational agents, according to game theory—is for Player 1 to defect at the first decision node, forgoing the possibility of far better payoffs to both players that would be gained by repeated reciprocal cooperation.

The reasoning is—or at least seems—quite straightforward. In game theory, both players are assumed to be instrumentally rational in the sense of invariably acting to maximize their own individual payoffs whenever they face a choice between alternatives that clearly yield different payoffs. They are also assumed to know everything about the game and their co-player's rationality, and to know that the co-player knows all this, and that the co-player knows that they know it, and so on (called *common knowledge* in game theory). This assumption can, of course, be relaxed for experimental studies. However, given the standard

game-theoretic assumptions, if the eighth decision node were to be reached, then a rational Player 2 would defect and choose STOP, because that would yield a better personal payoff (19) than choosing GO (16) at the game's natural end. However, at the seventh decision node, Player 1 would anticipate that a cooperative GO move would result in the co-player defecting at the eighth node. Player 1 would therefore face a choice between defecting at the seventh node and receiving a payoff of 16 or cooperating and receiving only 13 when Player 2 defects at the eighth and, being instrumentally rational, Player 1 would therefore defect and stop the game. Continuing backward, the same reasoning is applied to every move of the game, and this so-called *backward induction* (BI) argument ultimately requires Player 1 to defect and stop the game at the first decision node.

The BI argument establishes that the subgame perfect Nash equilibrium of the Centipede game is the unconditional STOP move by Player 1 at the first decision node. Technically, there are many Nash equilibria in the Centipede game, because decision nodes that cannot occur in practice are included in the analysis—for example, the third decision nodes even after Player 1 has defected on the first node, so that the third node is not reached in practice—but all of these Nash equilibria, most of which are purely hypothetical, involve Player 1 choosing STOP at the first node and Player 2 choosing STOP at the second node. The BI argument is less abstract and more realistic, inasmuch as it ignores the nodes that cannot be reached, and it shows that the only subgame perfect Nash equilibrium involves Player 1 defecting at the first node, stopping the game immediately. This is the game-theoretically rational outcome, deduced from BI reasoning. In the context of the much larger payoffs looming from the game's natural end, it is a highly counterintuitive solution, and it has been discussed frequently in the literature (e.g., Aumann 1995; 1998; Colman, Krockow, Frosch, & Pulford, 2017).

This article addresses fundamental questions about reciprocity and cooperation in human interactions using experimental Centipede games as a research paradigm. Comparing behavior across Centipede games of different lengths and designs, our results suggest that cooperation may increase in contexts of longer-term relationships, but only if the long-term nature is known to the decision makers in advance.

### 1.1. Previous experimental evidence

An increasing body of empirical research on the Centipede game shows reliable findings of rampant cooperation (Bornstein et al., 2004; Krockow, Colman, & Pulford, 2016; McKelvey & Palfrey 1992; Pulford, Krockow, Colman, & Lawrence, 2016), but only finite and relatively short Centipede games have been studied so far. As far as we are aware, the longest Centipede game ever used in a (still unpublished) experiment was Nachbar's (2014) 15-node game. However, given that Nachbar's study was based on a five-player design (as opposed to the standard two-player design), the length of the interaction still seems very limited, with each player facing a maximum of only three choices. The longest Centipede game in a published study was Nagel and Tang's (1998) twelve-node game. However, their game was presented in *normal form*, requiring the players each to make only a single decision indicating the latest decision node at which they would each defect if given the opportunity, rather than playing out the game move by move. This procedure therefore suppressed the sequential player interaction and reduced the length of time invested in each game.

Also, even though published Centipede games of two-player experiments have varied considerably in length (between three and twelve decision nodes), only two studies compared games of different lengths directly. Fey, McKelvey, and Palfrey (1996) reported earlier exit moves in shorter Centipede games, but their length differences were comparatively small. Furthermore, their study used highly competitive constant-sum games whose results may not be applicable to games with increasing-sum payoff functions, such as the version shown in Fig. 1. McKelvey and Palfrey (1992), who compared four-move and six-move exponential

games, also reported evidence for earlier defection in shorter games. A retrospective analysis of variance of McKelvey and Palfrey's data set reveals a significant difference between the standardized mean exit points of their high-stake four-move game ( $M = .51$ ;  $SD = .12$ ) and their low-stake six-move game ( $M = .61$ ;  $SD = .11$ );  $F(2, 65) = 4.11$ ,  $p < .05$ , partial  $\eta^2 = .11$ , indicating a medium effect size. However, given that their low-stake four-move and low-stake six-move game did not differ significantly, it is difficult to disentangle the respective effects of game length and stake size. Hence, further research needs to be done to arrive at a better understanding of the effects of game length.

### 1.2. Rationale for the present study

No research to date has investigated Centipede games with different termination rules such as unknown ends or random game termination, even though they could provide highly informative insights into decision-making situations marked by uncertainty or risk. A helpful point of reference could be the literature on the iterated or repeated Prisoner's Dilemma game (RPDG). The RPDG comprises a series of identical one-shot Prisoner's Dilemma games, all completed with the same co-player. This yields a repeated interaction resembling that created by the Centipede game, despite lacking certain unique features of the Centipede game. In the RPDG, the decision to defect does not terminate the entire interaction. Retaliation through strategies such as Tit for Tat is therefore possible. Furthermore, in the standard RPDG, decisions are made simultaneously by both players, thus lacking the sequential, reciprocal move structure of the Centipede game. Finally, the payoffs of the RPDG remain constant throughout the decision sequence and therefore cannot model the same variety of dynamic incentive structures as the Centipede game.

Despite these differences, research on the RPDG, which frequently used long and indefinitely repeated decision sequences (e.g., Rapoport & Chammah 1965), could provide interesting information on the importance of game length and termination rules. A particularly useful study is Normann and Wallace's (2012) comparison of RPDG's with different termination rules. Whereas the authors did not find significant differences between their treatment conditions, this fact could be attributed to a flawed design: the conditions were too similar (e.g., all games—even those with random termination rules—were programmed to continue for at least 22 iterations). Furthermore, each pair of participants played only a single RPDG sequence, preventing learning across games and increasing the possibility of reasoning mistakes.

Our study aimed to investigate the effects of game length and termination rule on cooperation in the Centipede game. To this end, we borrowed aspects of Normann and Wallace's (2012) research design. In order to investigate the effects of game length, our experiment included two game conditions with known lengths. Condition 1 used a game of standard length (eight moves), and Condition 2 introduced a longer game of 20 moves. Condition 3 of our study employed a game of fixed but unknown length. However, rather than indicating a minimum game duration to participants, as seen in Normann and Wallace's (2012) study, very neutral game instructions were used in order to avoid anchoring effects that could confound the results. Finally, one condition of random termination was included in which games could, in theory, continue indefinitely provided that the computer and both participants repeatedly chose GO. The likelihood of random termination by the computer was set to 1/6 in this fourth condition.

Despite the differences in termination rules, all four conditions of our experiment were characterized by the same subgame perfect equilibrium solution of defection at Node 1. Jiborn and Rabinowicz (2013) discussed BI in games of unknown ends and showed that knowledge of the exact game end is not necessary for this type of reasoning to be applied. As part of their argumentation, they shared the psychological point of view that random termination is unlikely to be interpreted by experimental subjects as infinite repetition,

because they know that they will not play the game forever. Thus, subjects may effectively treat the infinite games as finite sequences with unknown ends but (following Jiborn and Rabinowicz) with identical equilibrium solutions to standard Centipede games. Dal Bó and Fréchette (2018) have comprehensively reviewed studies of “infinitely repeated” Prisoner’s Dilemma games, using random termination rules. In these studies, subjects never know whether any round is the last but always know the probability that another round will be played. However, given the relatively high probabilities of termination used in previous studies, most “infinite” Prisoner’s Dilemmas were highly unlikely to continue for more than a few game rounds.

## 2. Method

### 2.1. Subjects

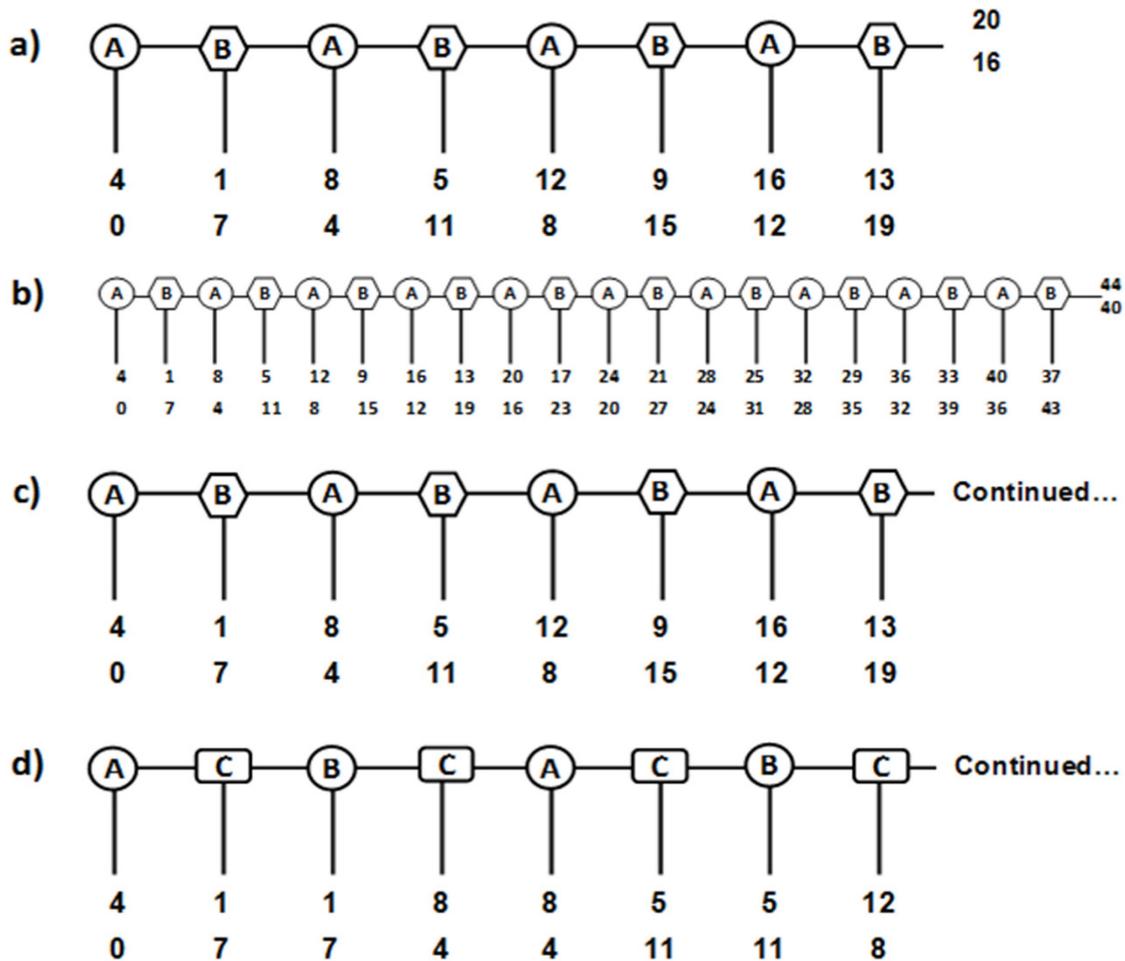
The sample consisted of 72 undergraduate psychology students from the University of Leicester—14 males and 58 females—with a mean age of 19.4 years ( $SD = 1.53$ ). The different proportions in gender were due to a largely female population of students. Although a balanced subject sample would have been preferable, previous experimental studies provided repeated evidence that gender does not affect decision making significantly in the Centipede game (e.g., Krockow, Pulford, & Colman, 2015; Krockow, Takezawa, Pulford, Colman, & Kita, 2017). All participants were incentivized by being entered into a lottery: for one person per testing session, payoffs from a randomly selected game completed during the experiment were converted to a cash payment in pounds sterling. Evidence for the validity of this incentive system has been provided by Bolle (1990), Cubitt, Starmer, and Sugden (1998), and Bardsley, et al. (2010). The mean cash remuneration of the four participants selected was £15.25 (approximately \$23.00).

### 2.2. Design

The participants were randomly assigned to one of four treatment conditions varying in the lengths and termination rules of their respective games (see Fig. 2): (a) Finite 8-node Centipede game; (b) Finite 20-node Centipede game; (c) Finite 20-node Centipede game with end unknown to participants; and (d) Indefinitely extended Centipede game with a random STOP probability of  $1/6$  after every move. This random STOP probability was chosen to match one of Normann and Wallace’s (2012) original termination rules.

Three dependent variables were calculated: the proportion of games terminated at Node 1, the proportion of games terminated at the natural end, and the standardized mean exit points of all games completed. The last variable was derived by dividing the mean exit point in each treatment condition by the respective game length (i.e., number of exit nodes). Calculating this standardized cooperation measure was necessary to enable the comparison of games with different lengths.

Each of the three variables provides a slightly different measure of cooperation, with the first indicating the proportion of games adhering to the subgame perfect Nash equilibrium solution, the second giving an estimate of pure altruism—paying a cost to benefit another individual—and the third measuring overall cooperation levels across all decision nodes. The last two variables could be calculated only for those conditions using games of finite lengths (Conditions 1–3).



**Fig. 2** Four treatment conditions: (a) Finite 8-node game; (b) Finite 20-node game; (c) Finite 20-node game with end unknown to participants; (d) Indefinitely extended game with random computer termination (probability = 1/6).

### 2.3. Materials

The study was conducted in a large computer laboratory. Each participant was seated at a computer and interacted in the Centipede game through a custom-made, web-based game application that included several detailed instruction slides and a color-coded, animated display of the relevant Centipede game. For Conditions 1 and 2, the full game was displayed on the participants' screens, whereas for Conditions 3 and 4 the participants saw only game excerpts of 8 nodes at a time, because their games were characterized by unknown or random ends. The rightmost node visible on the screen in Conditions 3 and 4 was followed by "[continued]", indicating that it was not necessarily the final decision point in the game. Whenever this node was surpassed by a GO move of the subjects, the previous game excerpt shifted to the right along the game tree to reveal the next decision node. At the same time, the leftmost decision node disappeared from the screen. In this way, the game window kept shifting to the right with every cooperative move. No indication was given before the final decision node in Condition 3 nor before the point of random computer termination in Condition 4. Consequently, subjects had no visual cues about the game length in these two conditions.

### 2.4. Procedure

Testing took place in four groups of 18 participants with each session lasting between 30 and 40 minutes. Participants were randomly assigned to the testing sessions. Each treatment condition was run in an individual session. It was impossible to run several treatments in parallel due to the different game lengths. In order to avoid confounding effects of testing sessions, personnel and test environment was identical across all four sessions. Two experimenters ensured that participants focused only on their own computer screens and did not talk or otherwise communicate with anybody else.

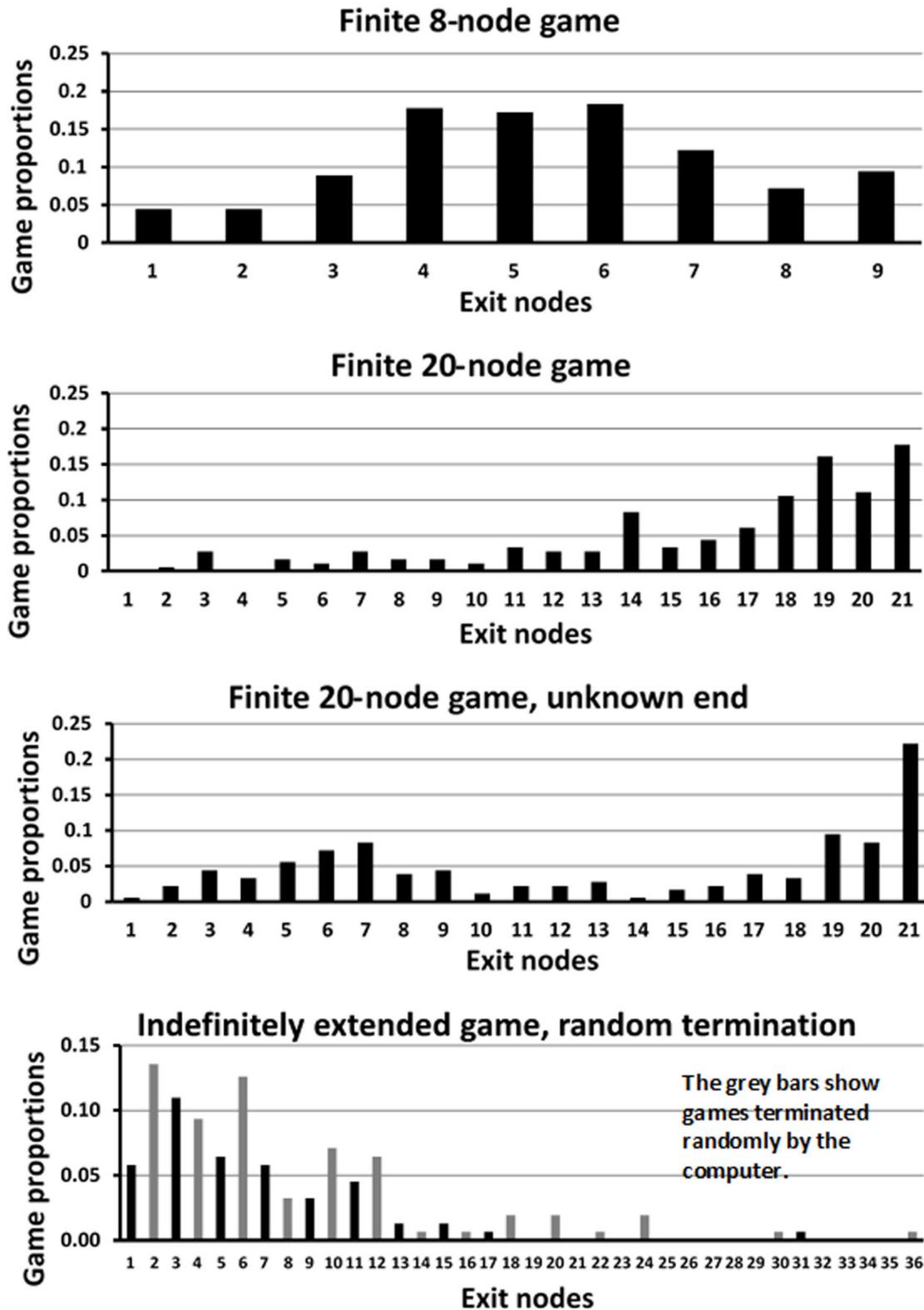
After filling in the consent form, participants received written task instructions on their computers, which they could read in their own time. Afterwards, they had the opportunity to ask questions about the rules and procedure. Then, the computer assigned them to a player role (Player A or B), in which they remained for the whole duration of the testing session. The participants did not know the identity of their co-players, and they were randomly re-paired after each game round. The web application provided them with real-time feedback on their co-players' moves, the outcome of each game, and the number of rounds completed. In the first three testing sessions (corresponding to Conditions 1–3), each participant completed 20 rounds of their respective Centipede games. The fourth testing session (Condition 4: indefinitely extended games with random termination), encountered problems with the computer software, resulting in some missing data after Round 14 increasing over the last few rounds.

The participants completed an average of 17.22 game rounds, with every participant finishing at least 14 rounds. Instead of the planned 180 games, data from only 155 games could be obtained in Condition 4, but this still provided sufficient power for the analyses required. At the end of each testing session, one participant was randomly drawn from the group for remuneration on a randomly selected game played during the session.

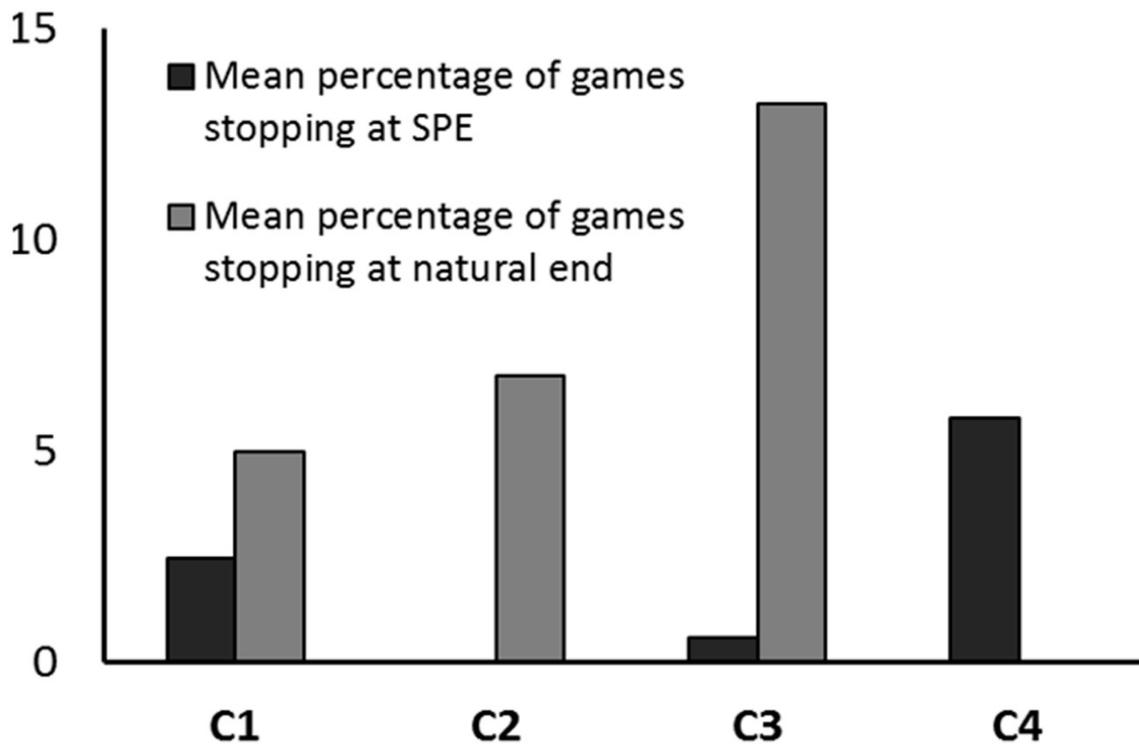
### 3. Results

Raw data are available in <https://ira.le.ac.uk>. The proportion of games ending at each exit point for the four game conditions is displayed in Fig. 3. For Condition 4 (indefinitely extended Centipede games with random termination probability of 1/6), all even-numbered exit points mark games ended by the computer and are therefore indicated by lighter shaded bars. Whereas Condition 1 (finite 8-node Centipede game) yielded a typical near bell-shaped distribution with a central peak at Exit points 4–6, the distributions of the other conditions were markedly different. Condition 2 (finite 20-node game) yielded a negatively skewed distribution, with its mode at the game's latest possible exit point of 21 and, additionally, a large proportion of games ending at Node 19. The distribution of Condition 3 (finite 20-node game with unknown end) shared this mode of 21, but additionally featured a smaller peak of STOP moves at Exit points 6 and 7. Finally, the distribution of Condition 4 (indefinitely extended game with random termination) was positively skewed, with a modal exit point of only 3 (when ignoring the games terminated by the computer).

Out of 695 Centipede games completed across all four conditions, only 18 (2.59%) were terminated at the subgame perfect equilibrium. A one-way ANOVA compared the four treatment conditions and found a significant effect on the mean percentage of games per participant that stopped at the first node,  $F(3, 71) = 11.070$ ,  $p < .001$ , partial  $\eta^2 = 0.33$ , see Fig. 4. Post-hoc pairwise comparisons between Condition 4 (random game termination) and each of the other treatment conditions yielded significant differences (Tukey HSD tests yielded  $p < .001$  for Conditions 2 and 3 and  $p < 0.05$  for Condition 1). The indefinitely repeated game Centipede with random computer termination yielded the highest percentage of games in line with equilibrium play ( $M = 5.78$ ;  $SD = 5.20$ ), followed by the finite 8-node game ( $M = 2.44$ ;  $SD = 3.82$ ), the finite 20-node game with unknown end ( $M = 0.56$ ;  $SD = 1.62$ ), and lastly the finite 20-node game where only a single game stopped at the first node.



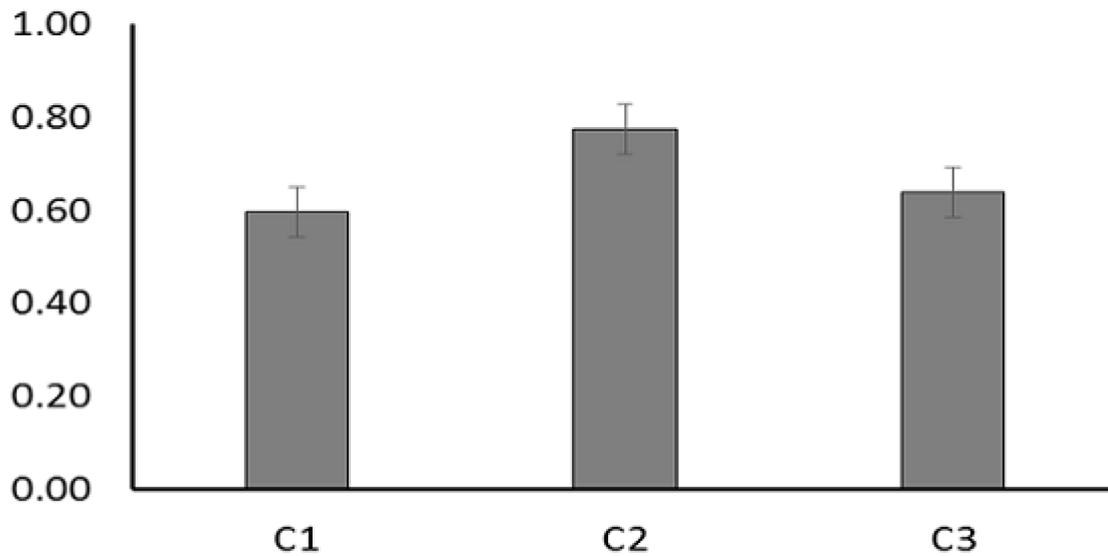
**Fig. 3** Game proportions across exit nodes for the four game conditions. For Condition 4 (indefinitely extended game with random computer termination), all games ended by the computer are shown using grey bars.



**Fig. 4** Mean percentages of games per participant stopping at the subgame perfect equilibrium (SPE) and at the natural end per condition (C1 = finite 8-node; C2 = finite 20-node; C3 = finite 20-node, unknown end; C4 = random termination). For C2, the percentage of games stopping at the SPE was zero. For C4, no percentage is given for the games stopping at the natural end, because this condition was characterized by random stop moves of the computer and had no fixed natural end.

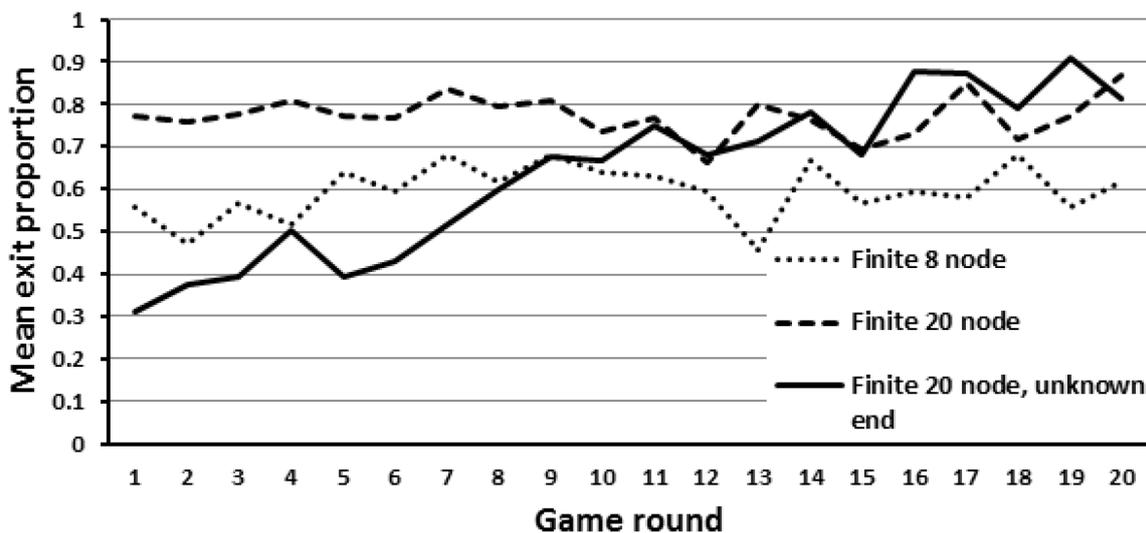
Out of 540 Centipede games with a finite number of exit nodes, 89 games (16.48%) ended at the game's natural end—Node 9 in case of the 8-node (8 refers to the number of decision nodes) game and Node 21 in case of the two 20-node games. Another one-way ANOVA compared the three respective treatment conditions, and found a non-significant effect on the mean percentage of games per participant stopping at the natural end,  $F(2, 53) = 2.316, p = .109$ , see Fig. 4. The finite 20-node game with unknown end produced the highest percentage of games reaching the natural end ( $M = 13.22; SD = 15.63$ ), followed by the finite 20-node game ( $M = 6.78; SD = 11.40$ ), and the finite 8-node game ( $M = 4.94; SD = 8.16$ ), but these differences failed to reach statistical significance.

As regards the standardized mean exit points calculated for Conditions 1–3 (all characterized by finite games), a one-way ANOVA showed that the experimental manipulation had a significant effect,  $F(2, 51) = 11.179, p < .001$ , partial  $\eta^2 = 0.30$ , see also Fig. 5. Post-hoc comparison indicated significant differences between Condition 2 (finite 20-node game) and both other treatment conditions (Tukey HSD tests yielded  $p < .01$  in both cases). The finite 20-node Centipede game produced the highest overall cooperation levels with the average game ending three quarters of the way through the possible game ( $M = 0.77; SD = 0.05$ ). This was followed by the finite 20-node game with unknown end ( $M = 0.64; SD = 0.14$ ) and lastly the finite 8-node game ( $M = 0.60; SD = 0.06$ ), both of which were typically terminated around two thirds of the way through the possible game.



**Fig. 5** Means of standardized mean exit points per participants for all three treatment conditions using finite games (C1 = finite 8-node; C2 = finite 20-node; C3 = finite 20-node, unknown end).

The standardized mean exit point per game round for Conditions 1–3 are displayed in Fig. 6. The line graphs for the two conditions with known game lengths do not show any discernible patterns of either increasing or decreasing scores with greater experience in the game. The data line of Condition 3 (finite 20-node game with unknown end), however, displays an overall increase of cooperation from an initial standardized mean exit point of around 0.3 to a maximum of over 0.9 on the 19th game round.



**Fig. 6** Mean exit proportions per game around across Conditions 1–3.

Time series analyses were carried out to further investigate these patterns across game rounds. The SPSS Expert Modeler identified an autoregressive integrated moving average (ARIMA) model with the parameters (0, 0, 0) for Conditions 1 and 2. These values of zero indicate that (a) the standardized mean exit points were not influenced significantly by the means from previous rounds, (b) there was no significant overall (linear or non-linear) data

trend, and that (c) the data did not include any random shocks impacting significantly on the standardized mean exit points to follow. Put simply, no temporal pattern could be found for the scores of the two conditions with known game lengths.

For the 20-node game with unknown end, however, the SPSS Modeler identified a different model: The best fit was an exponential smoothing model with a Holt linear trend, indicating a linearly increasing score pattern. The stationary  $R^2$  model fit statistic was calculated to estimate the model's goodness of fit. With an  $R^2$  value of .27, the model can explain almost 30% of the variance of the data, and indicates a superior fit to a simple mean model used as a baseline for comparison. Additionally, the Ljung Box statistic  $Q$  was calculated to test whether the model was correctly specified. The value of  $Q(16) = 15.91$ , ( $p = .46$ ) showed that no significant patterns in the data set were unaccounted for by the Holt linear model identified.

#### 4. Discussion

This study aimed to investigate whether game length and termination rule can influence decision making in the Centipede game. Cooperation levels were compared across four different treatment conditions including two conditions with finite game ends known to the participants (8-node and 20-node respectively), one finite 20-node condition with unknown game end, and an indefinitely extended condition with random game termination. Despite the indefinite nature and unforeseen loss of data from Condition 4, which complicated comparison with the three complete data sets of finite Centipede games from Conditions 1–3, the range of cooperation measures allowed for a comprehensive analysis of all data.

As in previous Centipede game research (e.g., McKelvey & Palfrey 1992; Krockow et al., 2016; Pulford et al., 2016), only a very small percentage of games adhered to the subgame perfect equilibrium and were terminated at Node 1. While all finite game conditions (Conditions 1–3) yielded mean percentages per participant of less than 2.5%, the indefinite games with random computer stopping produced a significantly larger percentage of almost 6% of games per participant stopping at the first node. It appears that the additional risk associated with a possible STOP move by the computer led participants to act more cautiously and defect earlier in this condition.

As regards the percentage of games reaching the game's natural end—a measure of unconditional cooperation and altruism—the finite game conditions all produced moderate to high numbers (Condition 4 had to be excluded from this analysis because of its indefinite nature). With a mean of 13% of games per participant reaching the final exit point in Condition 3 (finite 20-node game, unknown end), this was a higher result compared to the 7% in Condition 2 (finite 20-node) or the 5% found in Condition 1 (finite 8-node game). However, the difference failed to reach statistical significance—a result that can be attributed to the high data variability between participants that increased the standard deviation values.

While the results therefore have to be treated with caution, it is still notable that Conditions 2 and 3 of identical game length produced very different mean percentages of cooperative moves at the natural end. It is likely that the full information game of Condition 2 with its highly salient natural end improved BI reasoning, thereby incurring endgame effects of increased defection towards the final decision node. Condition 3, with incomplete information, on the other hand, lacked a salient end point because its natural end was concealed from participants, and this probably impeded BI reasoning.

Finally, the standardized mean exit point was considered as a measure of average cooperation levels in each game condition. Again, Condition 4 was excluded from the analyses due to its indefinite nature. Statistical comparison indicated that Condition 2 (finite, 20-node game) produced significantly more cooperation than Condition 3 (finite 20-node game, unknown end) and Condition 1 (finite 8-node game).

It thus appears that increasing the length of finite games may lead to an overall increase of cooperation if the natural end of the game is known. The effect may be due to the increased number of alternating, cooperative moves in the longer game, which is likely to invoke a stronger norm of reciprocity between participants, thereby promoting cooperation. Different theories have been proposed to explain the generally high levels of cooperation in Centipede games. A helpful model was provided by Jehiel (2005), who suggested that players form expectations about their co-players' likely moves at different nodes, and then select the best reply to the anticipated move. Furthermore, rather than forming different predictions for each individual node within a multi-stage game, players reduce their cognitive load by grouping together similar nodes and forming an expectation of average behavior at those nodes. When applying his model to the Centipede game, Jehiel suggested that subjects may group together earlier nodes in the game and predict those to elicit an average response of cooperative behavior from their co-players. In contrast, subjects may conceptualize later nodes as the "endgame" of the decision sequence where co-players will, on average, defect. Jehiel's model may not only explain the frequently observed deviations from the subgame perfect Nash equilibrium, but it could also help to understand the different cooperation levels found in shorter versus longer Centipede games. It is likely that the conceptualization of the Centipede endgame remains similar across different game lengths, comprising a relatively fixed number of only a few decision nodes. If the perceived endgame with expected defection by the co-player remains stable, the group of earlier decision nodes with expectations about their co-players' cooperative GO moves will consequently increase. This, in turn, could explain why subjects in the longer games tend to cooperate more frequently.

The observed difference between our two 20-node games with known and unknown end, whereby unknown ends reduced overall cooperation, is interesting. A possible explanation could be the increased uncertainty present in Condition 3 with unknown game end. The participants had to consider not only their co-players' likely actions but also the possibility of sudden game termination due to the unforeseen natural game end. When examining Fig. 3 which displays exit proportions at each decision node of the four different conditions, the relatively high percentages of STOP moves at Nodes 5, 6, and 7 in Condition 3 are striking. It is possible that the experimental design was responsible for this spike in defection. In the condition with unknown end, the total number of exit nodes could not be displayed in order to conceal the game length from the participants. Thus, the participants saw only excerpts of the game tree displaying eight decision nodes at a time. It seems likely that, with a view to managing the uncertainty of Condition 3, participants initially used the eight-node visual frame as an anchor for the expected game length. If they expected the game to end after eight moves, defection around Nodes 5, 6, and 7 would be in line with previous observations in shorter games.

This explanation links in with the findings of increased cooperation over time in this treatment condition. It seems likely that the majority of participants started out with a conservative expectation of the game length, partly influenced by the display, which they re-adjusted based on their experience during the experiment. Once they learned that the natural end lay beyond Node 8, their caution decreased and cooperativeness increased as a consequence, thus leading to later exit moves in later rounds of the game. This learning pattern also matches Nagel's (1995) qualitative learning direction theory that was later corroborated by Nagel and Tang's (1998) study of repeated Centipede games. The main finding was that participants who stopped a game in a particular round were more likely to increase the number of GO moves in the next round, whereas those who did not choose to stop were more likely to decrease their number of GO moves. In Condition 3 of the present experiment, participants started off cautiously, initially terminating the games around Nodes 5, 6, and 7. Following those early exit moves, they were likely to increase their GO moves in

the rounds that followed, perhaps testing out the limits of the game (the maximum game length). This process is likely to have led to their learning of more cooperative behavior over time.

Finally, even though Condition 4 was excluded from this statistical analysis, it is noteworthy that the exit moves in this indefinite game version with random stopping at a 1/6 probability followed a very different pattern different from the other three conditions. Even when disregarding the early STOP moves by the computer, it appears that games were terminated much earlier with participants' defection rates peaking at Node 3. This is an interesting finding and could be attributed to increased caution when faced with the additional risk through random game termination. A follow-up study by the same authors (Krockow, Colman, & Pulford, 2018) has investigated Centipede games with random termination rules in more detail, comparing three conditions with different STOP probabilities by the computer with a control condition of 24 nodes' length. This related study confirmed the subjects' sensitivity to the risk of game termination and showed how different STOP probabilities affect cooperation levels.

Taken together, the findings indicate that increasing the length of an interaction with a finite and known end can promote cooperation among decision makers. This is likely due to the increased opportunity for alternating cooperation and the norms of reciprocity invoked in longer games. Interestingly, introducing elements of uncertainty and risk in longer interactions seems to yield a decrease of cooperation. When the end is unknown, participants' decision making is guided by their own expectations about the game length (for example influenced by the framing of the decision context), and these may be adjusted over time in the light of increased experience with the decision task. When the end of the game is determined at random, it appears that participants adopt very cautious strategies and defect comparatively early, and higher proportions of games adhere to the subgame perfect equilibrium. The defection rates are likely to be influenced by the STOP probabilities of the computer, but further research needs to be conducted in order to investigate the effects of random termination rules in more detail.

## References

- Aumann, R. J. (1995). Backward induction and common knowledge of rationality. *Games and Economic Behavior*, 8(1), 6–19. doi: 10.1016/S0899-8256(05)80015-6
- Aumann, R. J. (1998). On the Centipede game. *Games and Economic Behavior*, 23(1), 97–105. doi:10.1006/game.1997.0605
- Bardsley, N., Cubitt, R. P., Loomes, G., Moffat, P., Starmer, C., & Sugden, R. (2010). *Experimental economics: Rethinking the rules*. Princeton, NJ: Princeton University Press.
- Bolle, F. (1990). High reward experiments without high expenditure for the experimenter. *Journal of Economic Psychology*, 11(2), 157–167. doi: 10.1016/0167-4870(90)90001-P
- Bornstein, G., Kugler, T., & Ziegelmeyer, A. (2004). Individual and group decisions in the Centipede game: Are groups more “rational” players? *Journal of Experimental Social Psychology*, 40(5), 599–605. doi:10.1016/j.jesp.2003.11.003
- Colman, A. M., Krockow, E. M., Frosch, C. A., & Pulford, B. D. (2017). Rationality and backward induction in Centipede games. In N. Galbraith, E. Lucas, & D. E. Over (Eds.), *The thinking mind: A Festschrift for Ken Manktelow* (pp. 139–150). London: Routledge.
- Cubitt, R., Starmer, C., & Sugden, R. (1998). On the validity of the random lottery incentive system. *Experimental Economics*, 1(2), 115–131. doi: 10.1007/BF01669298

- Dal Bó, P., & Fréchette, G. R. (2018). On the determinants of cooperation in infinitely repeated games: A survey. *Journal of Economic Literature*, 56(1), 60–114. doi:10.1257/jel.20160980
- Fey, M., McKelvey, R. D., & Palfrey, T. R. (1996). An experimental study of constant-sum centipede games. *International Journal of Game Theory*, 25, 269–287. doi: 10.1007/BF02425258
- Jehiel, P. (2005). Analogy-based expectation equilibrium. *Journal of Economic Theory*, 123(2), 81–104. doi: 10.1016/j.jet.2003.12.003
- Jiborn, M., & Rabinowicz, W. (2003). Reconsidering the Foole's rejoinder: Backward induction in indefinitely iterated Prisoner's dilemmas. *Synthese*, 136(2), 135–157. doi: 10.1023/A:1024731815957
- Krockow, E. M., Colman, A. M., & Pulford, B. D. (2018). Dynamic probability of reinforcement for cooperation: Random game termination in the Centipede game. *Journal of the Experimental Analysis of Behavior*, 109(2), 349–364. doi: 10.1002/jeab.320
- Krockow, E. M., Pulford, B. D., & Colman, A. M. (2015). Competitive Centipede games: Zero-end payoffs and payoff inequality deter reciprocal cooperation. *Games*, 6, 262–272. doi: 10.3390/g6030262
- Krockow, E. M., Pulford, B., D., Colman, A. M., (2016). Exploring cooperation and competition in the Centipede game through verbal protocol analysis. *European Journal of Social Psychology*. 46(6), 746–761. doi: 10.1002/ejsp.2226
- Krockow, E. M., Takezawa, M., Pulford, B. D., Colman, A. M., & Kita, T. (2017). Cooperation and trust in Japanese and British samples: Evidence from incomplete information games. *International Perspectives in Psychology*, 6(4), 227–245. doi: 10.1037/ipp0000074
- McKelvey, R., D., & Palfrey, T. R. (1998). Quantal response equilibria for extensive form games. *Experimental Economics*, 1, 9–41. doi: 10.1007/BF01426213
- Nachbar, G. (2014). Experimental findings and adaptive learning in a 5-player Centipede game. <http://digitalcc.coloradocollege.edu/islandora/object/coccc%3A9815>, Accessed 4 September 2016.
- Nagel, R. (1995). Unraveling in guessing games: An experimental study. *American Economic Review*, 85(5), 1313–1326. <http://www.jstor.org/stable/2950991>
- Nagel, R., & Tang, F. F. (1998). Experimental results on the Centipede game in normal form: An investigation on learning. *Journal of Mathematical Psychology*, 42(2/3), 356–84. doi: 10.1006/jmps.1998.1225
- Normann, H. T., & Wallace, B. (2012). The impact of the termination rule on cooperation in a prisoner's dilemma experiment. *International Journal of Game Theory*, 41(3), 707–718. doi: 10.1007/s00182-012-0341-y
- Pulford, B. D., Krockow, E. M., Colman, A. M., & Lawrence, C. L. (2016). Social value induction and cooperation in the Centipede game. *PLOS ONE*, 11(3), 1–21. doi: 10.1371/journal.pone.0152352
- Rapoport, A., & Chammah, A. M. (1965). *Prisoner's dilemma: A study in conflict and cooperation* (Vol. 165). University of Michigan press.
- Rosenthal, R. W. (1981). Games of perfect information, predatory pricing and chain store paradox. *Journal of Economic Theory*, 25, 92–100. doi: 10.1016/0022-0531(81)90018-1