Cooperation in Repeated Interactions:
A Systematic Review of Centipede Game Experiments, 1992–2016

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Abstract

Cooperation is a fundamental form of social interaction, and turn-taking reciprocity one of its most familiar manifestations. The Centipede game provides a formal model of such alternating reciprocal cooperation, but a backward induction argument appears to prove logically that instrumentally rational players would never cooperate in this way. A systematic review of experimental research reveals that human decision makers cooperate frequently in this game, except under certain extreme conditions. Several task, situational, and individual difference variables have been investigated for their influence on cooperation. The most influential are aspects of the payoff function (especially the social gain from cooperation and the risk associated with a cooperative move), the number of players, repetitions of the game, group versus individual decisions, and players' social value orientations. Our review of experimental evidence suggests that other-regarding preferences, including prosocial behavioural dispositions and collective rationality, provide the most powerful explanation for cooperation.

Keywords: backward induction, Centipede game, cooperation, game theory, reciprocity

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Cooperation is one of the most fundamental forms of human social interaction, and it plays a significant part in many areas of interpersonal, economic, and political life. In his last address as President of the Royal Society, Lord Robert May (2006) expressed the view that “the most important unanswered question in evolutionary biology, and more generally in the social sciences, is how cooperative behaviour evolved and can be maintained in human or other animal groups and societies” (p. 109). Cooperation frequently displays a pattern of repeated interactions in which Person A rewards Person B in some way, then B reciprocates by rewarding A, then A reciprocates by rewarding B again, and so on through several or many cycles of reciprocal cooperation. It is often reasonable to assume that each rewarding action incurs some cost c to the person performing it, financially, materially, or in terms of time, effort, or inconvenience, but that this cost is no larger than the benefit b to the recipient, so that $c \leq b$. Typical everyday examples include next-door neighbours taking turns looking after each other’s children to enable the parents to enjoy a night out, business associates taking turns providing each other with letters of recommendation for job applications, and academics taking turns providing feedback on each other’s research grant applications.

The Centipede game, introduced by Rosenthal (1981), provides a game-theoretic model of this class of repeated interactions. Formally, the Centipede game is a finite, *extensive-form* game (because players make their moves sequentially) with *complete information* (because they are fully informed about the specification of the game and both players’ payoff functions) and *perfect information* (because each player knows, when making a move, all previous moves in the game). It is usually represented by a game tree, such as the one depicted in Figure 1, its multi-legged appearance explaining its name, which is due to Binmore (1987).

Figure 1. Linear Centipede game.

In this two-player Centipede game, the top row shows a sequence of six *decision nodes*, represented by circles for Player A and hexagons for Player B, numbered in the order in which moves are made. Player A begins by deciding at the first decision node at the left whether to STOP the game immediately by choosing the line extending downward from the decision node, or to GO on with the game by choosing the line extending to the right, thereby handing the second move to Player B. If Player A stops the game at the first decision node, then the payoffs to Players A and B are 2 and 1 respectively, as shown in the first *terminal node* containing this pair of payoffs in the bottom row. If Player A decides to keep the game going by choosing a cooperative GO move, then Player A incurs the cost of cooperation c while benefitting Player B by an amount b . Player B can then either stop the game at the second decision node, with payoffs of 1 to Player A and 6 to Player B as shown in the second terminal node below, or continue the game by cooperating and handing the move back to Player A for a decision at the third decision node, and so on. If the game continues as far as the sixth and final decision node, and Player B chooses GO at that point, then the game comes to a natural end at the last terminal node on the right, with a payoff of 14 to Player A and 13 to Player B.

In formal game theory, the payoffs represent *von Neumann–Morgenstern utilities* that, by definition, reflect the players' true preferences, incorporating all selfish, altruistic,

generous, grateful, spiteful, and other considerations that might influence their choices; but it is common to interpret the numbers informally as pounds sterling, US dollars, euros, or other monetary units. When the Centipede game is used as an experimental game, the payoffs can only represent money or some other objective rewards, because experimenters have no access to players' subjective preferences and predilections. This problem is not considered fatal to experimental research, because it is generally assumed that monetary values reflect utilities fairly closely, at least for small amounts, but we shall revisit this issue in the Discussion section.

Varieties of Centipede Games

In the Centipede game shown in Figure 1, a GO move always decreases a player's payoff by one unit and increases the co-player's payoff by five units, hence $c = 1$, $b = 5$. This is an example of a *linear* Centipede game, because the payoff pot (the joint payoff of the player pair) increases linearly from one terminal node to the next—by four units in this case. This type of payoff structure corresponds to the type of reciprocal cooperation between next-door neighbours, business associates, or academics in the examples outlined earlier. The costs and benefits remain constant, but the pot increases linearly, because the *accumulated* joint payoff increases by a fixed amount after each move. The payoffs shown in Figure 1 represent these accumulated costs and benefits, and it is a merely technical aspect of the formalization that the payoffs are realized only when one of the players stops the game.

The two principal alternative payoff functions for Centipede games are the *exponential* and *constant-sum* versions shown in Figure 2 (a and b respectively). In exponential Centipede games (McKelvey & Palfrey, 1992), the pot increases exponentially, doubling (or increasing by some other fixed proportion) from one terminal node to the next. In constant-sum Centipede games (Fey, McKelvey, & Palfrey, 1996), the pot remains constant and GO moves generate no social gains, but the players' shares become increasingly

asymmetric, with the player who stops the game earning an ever-increasing share of the pot. Another less frequently studied version, the *Take-it-or-leave-it* Centipede game (Reny, 1992, Krockow, Pulford, & Colman, 2015), also called *Take or pass* game (Huck & Jehiel, 2004), is shown in Figure 2c. In this version, whether the payoff function is linear or exponential, a player who defects invariably receives the entire payoff pot, leaving nothing for the co-player.

a.

b.

c.

Figure 2. Principal payoff function variations of nonlinear Centipede games: (a) exponential, (b) constant-sum, (c) Take-it-or-leave it (exponential version).

It is worth mentioning that any of the Centipede games outlined so far could be modified by setting both payoffs at the last terminal node to zero. This modification, introduced by Aumann (1992), ensures that the players face the problem of deciding *when* to defect (before a deadline), without having to consider *whether* to defect, because the option of cooperating at every opportunity is effectively ruled out, but in other respects the basic strategic properties remain the same (Krockow, Pulford, & Colman, 2015).

These variations provide models of reciprocal interactions with different payoff structures (static costs and benefits, increasing costs and benefits, increasing conflict over a finite resource, winner-takes-all conflicts, and reciprocal cooperation with deadlines) reflecting many everyday strategic interactions. To illustrate how they could arise in real-life strategic interactions, we offer the following hypothetical scenarios. For simplicity and comparability, our examples all focus on medical research, but the game-theoretic models are potentially relevant to any area of strategic interaction.

First, consider two hypothetical researchers who are collaborating on the development of a new drug. They take turns in running experiments to study treatment efficiency and side-effects. Each experiment is costly to the researcher who performs it in time and resources (e.g., laboratory supplies and research staff). However, the prospective value of the drug increases with each experiment. At any point during this continuing interaction, either of the researchers has the option to defect by ending the collaboration, writing up the results and publishing them, retaining the privilege of first authorship. Although the personal benefit from the research project is larger for the defector, both researchers receive some benefit and, crucially, both are ultimately better off as a result of their collaboration. In this example, it appears reasonable to assume that the researchers' costs and benefits remain more or less constant, but the accumulated value of the research findings increases steadily with every

experiment conducted. If these assumptions are met, then the scenario could be modelled by a Centipede game with a linearly increasing payoff function, as in Figure 1.

Second, consider a slight variation of the scenario above. Imagine a different research project, such as the development of a revolutionary new cancer drug. Let us suppose that the potential value of the drug is initially small, because of the high probability of failure, but that each successful experiment increases it exponentially, doubling its potential value at each stage, for example. Given this accelerating increase in value, the risk associated with cooperation and the loss resulting from the collaborator's defection are larger than in the previous scenario, and both increase after each step in the process. But if the two researchers cooperate nevertheless, the ultimate benefits to both are larger than before. A scenario with this incentive structure could be modelled by a Centipede game with an exponentially increasing payoff function (Figure 2a).

Third, consider the following scenario. A university Dean of Medicine has a small pot of money available for research, and he offers to split it equally between two departments, Neurology and Cardiology. The heads of both departments argue that a half share is too small to be put to any tangible use, and each argues for a larger share of the pot. In an effort to be fair and transparent, the Dean decides to make a sequence of proposals for splitting the pot, the first slightly favourable to Neurology, the second slightly more favourable to Cardiology, and so on, each proposal offering a more unequal split than the last. The Dean explains that as soon as one of the department heads accepts a proposed split, it will be implemented immediately, and the other will have to accept it. A scenario of this kind could be modelled by constant-sum Centipede game (Figure 2b).

Fourth, consider the following variation of the second scenario. Once again, two researchers are collaborating on the development of a new drug and obtaining findings that are increasing its potential value exponentially. However, instead of the temptation to

publish, the researchers are faced with lucrative offers from industry. A pharmaceutical company offers them increasingly large sums of money for the rights to their discovery and its commercialization. Assume that as soon as one of the researchers defects by accepting an offer, the drug development is terminated and the defector is the only one to benefit from the scientific discovery. This is a more competitive variation of the two previous examples, and the closest game-theoretic model would be a Centipede game with winner-takes-all payoff function (Take-it-or-leave-it game), as illustrated in Figure 2c.

Fifth and last, consider the following variation of the first scenario. Once again, two researchers in the UK are working on a medical research project that yields a higher payoff to the one who defects first by publishing the findings, but in this version both receive zero payoffs to both if a deadline is missed. Let us assume that a Swiss laboratory, working to a published schedule, is racing to develop a similar drug, and that if this rival laboratory publishes its findings first, then the work of the UK researchers immediately loses all value and becomes unpublishable. In this scenario, the two researchers know that one of them must defect and publish before the deadline if they are to avoid a highly deterrent outcome with zero payoffs to both. This type of scenario might be best modelled by a Centipede-type incentive structure with a deadline (zero payoffs at the end).

Multi-player versions (with three or more players) of any of the games so far discussed have also been devised in which a player who chooses STOP receives a larger payoff than the co-players, who in turn typically receive equal smaller payoffs (e.g., Rapoport, Stein, Parco, & Nicholas, 2003). All Centipede games share fundamental strategic properties in common, encapsulating varieties of repeated reciprocal cooperation that are familiar features of myriad social relationships. They provide more realistic models of reciprocal cooperation than the frequently studied Prisoner's Dilemma game, because decisions in a Centipede game are sequential, and players have knowledge of their co-

players' moves—properties that are common to most everyday reciprocal interactions—whereas the Prisoner's Dilemma is a static game in which each player makes a single decision without knowledge of what the co-player has chosen. Some of these shortcomings are overcome in iterated or repeated Prisoner's Dilemma games, but in a series of identical one-shot Prisoner's Dilemma games with the same co-player, decisions are still made simultaneously. This property renders the game an unsuitable model of the type of sequential reciprocal cooperation being considered here. The repeated Prisoner's Dilemma game is also different in other ways. Defection does not terminate the entire interaction, as in the Centipede game, and retaliation through strategies such as Tit for Tat is possible. Finally, the payoffs of the repeated Prisoner's Dilemma game remain constant throughout the decision sequence and therefore cannot model the same variety of dynamic incentive structures as the Centipede game.

The Centipede game, in all its varieties, induces both cooperative and competitive motives in players, because at every decision node, opting to continue is a cooperative move benefitting both players if cooperation is reciprocated, and opting to stop the game is an uncooperative defecting move, because it benefits only the player who stops. It is obvious that both players benefit in the long run from reciprocal cooperation, because joint payoffs increase as the game continues (except in constant-sum versions); but it is also clear that a player always earns a better payoff by defecting than by cooperating if the co-player defects at the next decision node. In order to maximize their own payoffs when interacting with untrustworthy partners, players need to get their defection in first, and it is thus clear that trust, trustworthiness, risk-taking, and cooperation are key psychological factors at work in any Centipede game.

Backward Induction

What interests game theorists most about the Centipede game is its highly paradoxical—in fact, almost unbelievable—game-theoretic solution. The solution is arrived at through a form of reasoning called *backward induction* (BI) because of its resemblance to mathematical induction. The BI argument is based on two assumptions: (a) that both players are instrumentally rational in the sense of invariably choosing an option that maximizes their own payoff; and (b) that the rationality of both players and the specification of the game are *common knowledge* (Aumann, 1976; Lewis, 1969), in the sense that both players know them, both know that both know them, both know that both know that both know them, and so on *ad infinitum*. In fact, a player needs only one iteration of common knowledge less than the number of decision nodes in the game to solve it, as we shall see, but full common knowledge implies infinite iterations.

From the seemingly innocuous assumptions (a) and (b) it turns out, astonishingly, that Player A will defect at the first decision node in Figure 1, with payoffs of only 2 to Player A and 1 to Player B. The argument applies equally to any of the games in Figure 2, in which the players would forgo even larger payoffs, and even to games with zero payoffs at the last terminal node, but for simplicity we explain it here using the game in Figure 1 as the example.

The argument begins by examining what would happen if the final decision node were to be reached. The first assumption (a) ensures that Player B would defect at Node 6, because that would maximize Player B's payoff, given that STOP results in a personal payoff of 14 whereas GO results in a payoff of 13. If the fifth decision node were to be reached, then the second assumption (b) implies that Player A would know that a cooperative move would result in Player B defecting at the following (sixth) node, and the first assumption (a) ensures that Player A would therefore defect and stop the game immediately, because that would maximize Player A's payoff, given that the personal payoff of 10 at Terminal Node 5 is

greater than the payoff of 9 at Node 6. The argument unfolds in the same vein, step by step, with one additional level of common knowledge required at each successive backward step, until it forces the conclusion that Player A would defect and stop the game at the very first decision node. Although a payoff of 2 is meagre compared to those on offer further to the right, a cooperative opening move by Player A would result in Player B defecting at the second decision node, and defecting is therefore better for Player A because $2 > 1$. Defection at the first decision node is the unique *subgame-perfect* (because it is proved by BI) *Nash equilibrium* of the game, a Nash equilibrium being an outcome in which neither player could have done better by choosing differently, given the strategy chosen by the co-player.

The number of decision nodes in this game could be extended to any finite number, with enormous riches available to players who cooperate reciprocally, and the BI argument would still hold, apparently proving that rational players would never cooperate, nor would they cooperate in any of the games in Figure 2 or extensions of them. Aumann (1992) described this conclusion as “among the most disturbing counterintuitive examples of rational interactive decision theory” (p. 219), and the validity of BI has attracted much theoretical and mathematical discussion (e.g., Aumann, 1995, 1998; Ben-Porath, 1997; Binmore, 1987, 1994, 1996; Broome & Rabinowicz, 1999; Busemeyer & Pleskac, 2009; Colman, Krockow, Frosch, & Pulford, 2016; Kuechle, 2009; Reny, 1992; Stalnaker, 1998; Sugden, 1992; Zauner, 1999). We are not concerned here with this normative problem but are focused instead on reviewing experimental evidence related to the positive or descriptive question of how human decision makers actually behave in experimental Centipede games, irrespective of the validity or otherwise of the BI argument.

Overview

It is striking that approximately four times as many articles in peer-reviewed journals in the *Social Science Citation Index* have been devoted to discussing theoretical issues

surrounding the Centipede game than in reporting relevant experimental findings. Up to the time of writing this review, data from 25 peer-reviewed Centipede experiments have appeared, and we have also located a number of unpublished studies. Most experimenters have collected data in laboratory testing sessions with many subjects present at the same time. Most (but not all) have studied repeated or iterated Centipede games with anonymous pairing—players kept ignorant of the identity of their co-players—and among these, most (but not all) have used random re-pairing after each repetition or round. In studies that have used anonymous and random re-pairing, it is not always clear from the written reports whether the best practice of *perfect stranger matching* was used. In perfect stranger matching, players know that the probability of being matched more than once with the same anonymous co-player is zero, and this removes any incentive to manage their reputations by acting in particular ways in one round in the hope of influencing their co-players' behaviour in a later round.

The experiments that have been reported all show wild deviations from the subgame-perfect solution of defecting at the first decision node. Very few subjects in the role of Player A defect immediately, and frequent cooperation is typically observed. A conspicuous minority of players even cooperate at the last decision node, without any possibility of personal gain. Cooperation at the last decision node is of special theoretical interest, because it meets both of the standard definitions of *altruism* in the scientific literature. According to a widely accepted psychological definition, altruism is behaviour motivated solely to benefit another individual; and according to the standard biological and economic definition, altruism is paying a cost to provide a benefit to another individual (Clavien & Chapuisat, 2013). Cooperating at the last decision node—or at the penultimate decision node in games with zero payoffs for both players in the last terminal node—is altruistic according to either of these definitions.

The most frequently examined dependent variable has been the mean exit node, early exiting or defection being interpreted as evidence of game-theoretic rationality and late defection indicating (formally irrational) cooperation. When the Centipede game is played using the traditional *direct response method*, which includes players taking turns making choices and receiving real-time feedback on their co-players' moves, the sequential-move structure and interdependence of players' decisions mean that even the most cooperative player can never reach late exit nodes when paired with an early-defecting co-player. Consequently, exit nodes provide accurate information about only the defecting player's cooperativeness. For the co-players, exit nodes can provide only minimal values indicating the lower limits of their cooperativeness.

Eight studies included in this review used different methods to elicit exit moves. Le Coq, Tremewan, and Wagner (2015), for example, used Selten's (1967) *strategy method*, requiring subjects to specify in advance their planned moves at each decision node in the game, the resulting strategy vector providing full information about each participant's planned decision profile including the exit node. This methodology omits any actual sequential interaction and yields independent data points for all players, rather than just for the earlier defector in each pair. Using a variation of this strategy method, Nagel and Tang (1998) and Baghestanian and Frey (2014) presented Centipede games in *reduced normal form*, asking players to indicate their preferred exit node in the game as opposed to their full strategy vector. The two methods—the direct response method and the strategy method (with its variations)—have disadvantages as well as advantages, as discussed in previous literature (e.g., Brandts & Charness, 2011), and specific aspects will be highlighted when we review these studies.

A further word of caution is in order regarding the interpretation of moves in a Centipede game. Although a move that continues the game is commonly labelled *cooperate*

and a move that stops the game *defect*, there are several motives that can lead to these moves. This comment could also be made about the Prisoner's Dilemma game, in which the same labels (cooperate and defect) have become conventional. In the Centipede game, early exiting may be motivated by competitiveness, lack of trust, or fear, among other motives, and late exiting by considerations far removed from cooperativeness, including a purely individualistic motive to maximize personal payoff by defecting as late as possible. The range of motives that may account for different moves in the Centipede game was explored in a qualitative study using verbal protocol analysis (Krockow, Pulford, & Colman, 2016), the results of which will be discussed in more detail later in this review.

The remainder of this article is structured as follows. In the next section, we explain the methodology used for accessing the relevant experimental studies and the criteria used for including them in the review, and we outline the independent and dependent variables that have been investigated. The following sections present our review of results, starting with a quantitative summary of measures from the published studies included in the review. Using a classification adapted from Vinacke (1969), the three sections that follow contain narrative reviews of the effects of *game variables*, *situational variables*, and *individual difference variables*. Game variables are features of the particular Centipede games used in the experiments, including variations in payoff function, monetary incentives associated with the payoffs, information available to players about co-players' payoffs, decision space (the options from which players choose their moves), number of players (two-player or multi-player), and game length (number of decision nodes and number of rounds of play). Situational variables are aspects of the social or experimental environment in which the games are played, including individual versus group decision making, ingroup and outgroup interactions, effects of extraneously introduced extreme players, and so on. Individual difference variables are variations among the subjects or players, including differences in

cognitive ability, other-regarding preferences, and personality traits. After reviewing the effects of these variables, the article concludes with a discussion drawing the threads together and presenting some general conclusions about why people cooperate in repeated reciprocal interactions.

Method

Search Procedure and Inclusion Criteria

In this review, we summarize, structure, and evaluate all Centipede game experiments that we have managed to locate. We retrieved the relevant publications initially through systematic online searches via Google Scholar, the Social Sciences Citation Index, EconLit, and PsycINFO, using the search term *Centipede game*. Following this initial trawl, we performed a citation search for articles that have cited McKelvey and Palfrey (1992), the first published report of a Centipede experiment. Finally, we contacted every email-accessible Centipede researcher identified through previous searches and enquired about any further unpublished experiments.

Both published and unpublished experiments are included in the main text of this review, but unpublished experiments are excluded from our quantitative comparisons and key statistics. To minimize the risk of including unreliable or untrustworthy data, the calculations of underlying quantitative measures are based exclusively on the results of experiments reported in published, peer-reviewed articles. The Appendix contains a comprehensive synopsis of all retrieved studies, distinguishing between published and unpublished experiments and indicating the sources.

To be included in our review, a study had to report empirical findings from a Centipede game using human subjects. To qualify as a Centipede game, a game had to be characterized by the type of sequential move structure outlined in the Introduction and to have a payoff function satisfying the formal properties defined in the subsection that follows.

Only games with at least three decision nodes and fixed payoff functions and were included. Centipede games share many features in common with iterated Trust games (e.g., Güth, Ockenfels, & Wendel, 1997; Ho & Weigelt, 2005) and iterated Ultimatum games (e.g., Güth, Ockenfels, & Wendel, 1993; Ochs & Roth, 1989), but most of these have only two decision nodes, and/or lack the predetermined payoffs at each terminal node that are characteristic of Centipede games.

Dynamic games with Centipede-like payoff functions have also been investigated in the area of social and developmental psychology, where they have been used to infer beliefs about co-players and theory of mind in adults (e.g., Goodie, Doshi, & Young, 2012; Hedden & Zhang, 2002; Meijering, van Rijn, Taatgen, & Verbrugge, 2012; Zhang, Hedden, & Chia, 2012) and children (e.g., Flobbe, Verbrugge, Hendriks, & Krämer, 2008). However, whereas most of these studies made important contributions, their immediate relevance to Centipede research is limited, because most presented research subjects with a large variety of strategic games only few of which actually satisfied this review's inclusion criteria. Because it was impossible to tease out the data derived from pure Centipede games, these studies have been excluded from the review.

Definition of Centipede payoff function. Both constant-sum and increasing-sum Centipede games were included in this review (no experiments with decreasing-sum games have appeared), provided that their payoff functions satisfied certain defining properties. Using the expression $x(t)$ for the payoff x to Player A at terminal node t (where “terminal node” refers to the game's end point that is reached when either player chooses STOP at a decision node), and $y(t)$ for the payoff y to Player B at terminal node t , our defining properties for Centipede payoff functions were as follows:

1. At every odd-numbered terminal node, $x(t) \geq y(t)$, and at every even-numbered terminal node, $y(t) \geq x(t)$. This means that a player who defects invariably receives a payoff at least as great as the co-player's.

2. At every odd-numbered terminal node, $x(t) > x(t + 1)$ and at every even-numbered terminal node, $y(t) > y(t + 1)$. A player invariably receives a strictly larger payoff by defecting than by cooperating if the co-player defects at the following decision node.

3. At every odd-numbered terminal node, $x(t) < x(t + 2)$, and at every even-numbered terminal node, $y(t) < y(t + 2)$. A player invariably receives a strictly smaller payoff by defecting immediately than by cooperating and then defecting (if possible) at the next available opportunity.

4. For Centipede games with zero payoffs to both or all players in the last terminal node, if the game has k terminal nodes, then properties 1–3 apply up to the $(k - 1)$ th terminal node only.

Some experimental Centipede games included unorthodox features, notably decisions made simultaneously (Cox & James, 2012) and games with continuous time replacing discrete decision nodes, in which players could defect whenever they wished (Murphy, Rapoport, & Parco, 2006). These features, which will be discussed more fully in the Results section, were formalized for the purpose of this review by integrating and displaying them within the decision trees of standard Centipede games. For example, the STOP moves made in games without discrete decision nodes, where participants received payoffs associated with their respective stop-times, were retrospectively divided up to correspond to a distinct node structure and allow comparison with other experiments.

Independent and Dependent Variables

Independent variables. Most published and unpublished experiments have investigated the effects of one or more independent variables on behaviour in Centipede

games. We summarize the results under these headings Game Variables, Situational Variables, and Individual Difference Variables below.

Indices of cooperation. To facilitate comparison across experiments, we recorded three main indices of cooperation for each treatment condition in the experiments reviewed. We provided scores for these indices regardless of the study's elicitation method (i.e., direct response method or strategy method). Because the scores are not completely comparable, we marked each treatment condition using (a variation of) the strategy method with an asterisk.

First, to quantify adherence to the subgame-perfect Nash equilibrium solution, we recorded the percentage of games terminating in the equilibrium outcome (in the vast majority of cases, these were games ending at the first terminal node). For games played using the strategy method, percentages of STOP moves at Node 1 by participants in the role of Player A were calculated.

Second, to assess the prevalence of altruism, we recorded the percentage of games reaching the last terminal node (the game's natural end). It should be noted, however, that for games played using the direct response method, the percentage of games reaching the final terminal node can never be a precise measure of altruism and is likely to underestimate its prevalence within a given sample. The reasons are that, for this elicitation method, the statistic can measure altruism only in subjects assigned the role of Player B (or Player C in the three-player version of the game), because only this player can ever get the chance to make the final, altruistic move. Furthermore, many games involving an altruistic participant in the role of Player B could be stopped by less cooperative co-players long before the end, in which case any altruistic intentions of Player B would go unnoticed. With regard to studies using the strategy method, the total percentage of players (Players A and B) choosing GO at their final decision node was calculated.

Third, to provide a measure of average cooperation levels, we calculated the mean exit node in each treatment condition. Because experimental games varied in length, we divided this mean by the total number of terminal nodes, to provide an index of *standardized mean exit points* ranging from 0 to 1.

Results

A synopsis of the results from this review is presented in the supplemental materials. The synopsis covers all published and unpublished studies on Centipede games to date. It lists design features and independent variables of the respective studies, and provides a summary of the main cooperation measures.

Summary Measures

First and last exit nodes.¹ Figure 3 shows the percentages of games ending at the first and last decision nodes. Findings closest to the game-theoretic equilibrium solution were reported by Cox and James (2012) in a study of a 10-move linear Take-it-or-leave-it Centipede game with an unorthodox move structure (simultaneous moves under time pressure). Next closest to the game-theoretic solution was a study of expert and grandmaster chess players using a six-move exponential Centipede game (Palacios-Huerta & Volij, 2009), and experiments using 6-move and 10-move constant-sum Centipede games (Fey, McKelvey, & Palfrey, 1996). The vast majority of experiments show large deviations from the game-theoretic solution. In some treatment conditions, not a single game outcome conformed to the game-theoretic prediction.

Figure 3. Game percentages ending at first and last exit nodes across 72 treatment conditions (“condition” abbreviated “C”). All games played using (a variation of) the strategy method are marked with an asterisk.

Furthermore, many experiments provide evidence for substantial proportions of altruists. The high percentages of altruists in Gerber and Wichardt's (2010) study (up to 56%) in eight-move linear Centipede games are easily explained by "welfare-enhancing instruments" used in the experiment—options to buy insurance against termination by the co-player or to pay a small price in return for offering the co-player a bonus for not terminating the game. Bornstein et al.'s (2004) Condition 1, using a six-move linear Centipede game, also yielded a very high percentage of altruistic moves (16.67%). However, it is important to note that the total number of games included in this condition was comparatively small, so that 16.67% translates into only three games with altruistic terminations. It is noteworthy that studies using the strategy method (e.g., Baghestanian & Frey, 2014; Le Coq et al., 2015; Nagel & Tang, 1998) were marked by very high percentages of altruistic moves. This can be explained by the more complete and accurate results yielded by the strategy method, which reflect both players' levels of altruism and are independent of the co-players' choices.

Standardized mean exit points.¹ Figure 4 provides an overview of the distribution of standardized mean exit points across different experiments and treatment conditions. In this figure, treatment conditions are classified according to payoff function (linear, exponential, or competitive variations including constant-sum and Take-it-or-leave-it payoff functions). It is immediately obvious that a high proportion of experiments have focused on exponential Centipede games. On average, competitive games seem to elicit the lowest proportions of GO moves and linear games the highest. The rank order of standardized mean exit points presented in Figure 3 largely mirrors the ranking of results both according to percentages reaching only the first terminal node: $r_s(111) = -.454, p < .001$, and according to percentages reaching the last terminal node: $r_s(111) = .815, p < .001$.

Figure 4. Standardized mean exit points across 72 treatment conditions (“condition” abbreviated “C”), classified by payoff function types. Competitive Centipede game variations include all constant-sum and Take-it-or-leave-it Centipede games. All conditions played using (a variation of) the strategy method are marked with an asterisk.

Game Variables

Payoff Function. The experiments under review used Centipede games that vary considerably in their payoff functions. Several other aspects of the task presented to the subjects also differed between experiments and between treatment conditions within experiments. In the paragraphs that follow, we review the effects of these variables on the dependent variables that we have identified.

Constant-sum and increasing-sum games. From a theoretical point of view, the most important factor differentiating Centipede game payoff functions is the distinction between constant-sum, on the one hand, and increasing-sum, whether linear or exponential, on the other. Linear or exponential decreasing-sum payoff functions are theoretically possible, but no experiments investigating them have been reported. The reason why this distinction is so important is that, according to basic principles of game theory, two-player constant-sum games are *strictly competitive*, and this implies that there is no scope for mutually beneficial cooperation and no social gain from GO moves: players can only struggle for shares of a fixed pot, one player's gain invariably being equal to the other's loss. Because GO moves are frequently interpreted as cooperative, and cooperation is obviously an important motive for choosing GO, we should expect earlier defection in constant-sum than other Centipede games.

A different reason for the importance of distinguishing between increasing-sum and constant-sum games was provided by Pulford, Colman, Lawrence, and Krockow (2016). These authors pointed out the potential applicability of fuzzy-trace theory (Reyna & Brainerd, 1991, 1995), which suggests the formation of mental *gist representations* when one is presented with an abstract decision context. To simplify their choice process and avoid storing detailed payoff information, players in the Centipede game may generate gist representations to guide their decisions. Such representations are likely to associate STOP

moves with the certainty of small payoffs and GO moves with the possibility of larger payoffs, thus tempting players to choose GO repeatedly. This gist seems highly compelling in increasing-sum Centipede games, where the payoffs associated with early exit nodes are appreciably smaller than those associated with later exit nodes. In constant-sum games, on the other hand, the potential gains to be reached by choosing GO tend to be comparatively small, thus decreasing the temptation to choose GO and increasing defection rates.

Only a small number of experiments have investigated constant-sum Centipede games. Fey, McKelvey, and Palfrey (1996) reported that decision making in their six-move constant-sum game was closer to the game-theoretic solution than in previous studies using increasing-sum games. The relative frequency of defection at the first decision node of their game was .59—much higher than the relative frequency of .01 in McKelvey and Palfrey's (1992) six-move exponentially increasing game. Relative frequencies of defection increased with every decision node, and 45 subjects out of 176 chose STOP at every opportunity. Kawagoe and Takizawa (2012) confirmed the results of Fey et al. in a direct replication and comparison of the original two games.

The effect of constant-sum versus non-constant-sum payoff functions reported by Fey et al. (1996) and Kawagoe and Takizawa (2012) may be confounded with incentive effects. Fey et al. used very low stakes with a maximum individual payoff of \$2.92. In McKelvey and Palfrey's (1992) game, on the other hand, it was possible to win up to \$25.60 in a single game. Payoff function was thus confounded with stake size, and this raises the possibility that the different response patterns in games with different payoff functions may have been caused by the smaller incentive to choose GO in the constant-sum game in both experiments.

Bornstein, Kugler, and Ziegelmeyer (2004) solved this methodological problem by controlling for stake size in their comparison of constant-sum and linear Centipede games, and even with this additional control they found a significant difference between the two

payoff functions. Not a single six-move constant-sum game reached the last three terminal nodes, compared to an overwhelming 88% in the increasing-sum condition. Pulford, Colman, Lawrence, and Krockow (2016) compared eight-move constant-sum Centipede games with different versions of linearly increasing Centipede games—all carefully controlled for stake size—and found similar differences to those reported by Bornstein et al., with constant-sum games eliciting significantly less cooperation than increasing-sum versions. These findings were further corroborated by two as-yet unpublished experimental comparisons of linearly increasing and constant-sum Centipede games with ten moves and three moves respectively (Atiker, Neilson, & Price, 2011; Wang, 2015). Taken together, the results suggest that constant-sum and increasing-sum Centipede games provide significantly different contexts for decision making, despite their identical equilibrium solutions.

Take-it-or-leave-it payoff function. Another class of payoff functions that induces highly competitive behaviour includes those in which a player who defects invariably receives the entire accumulated payoff, leaving nothing for the co-player. Only five experimental studies have investigated such Take-it-or-leave-it Centipede games (Cox & James, 2012; Cox & James, 2015; Huck & Jehiel, 2004; Krockow, Pulford, & Colman, 2015; McIntosh, Shogren, & Moravec, 2009). Cox and James reported one of the lowest levels of cooperation ever found. This must be due, at least in part, to their highly competitive Take-it-or-leave-it payoff function, but it is difficult to draw clear conclusions from their study on account of various confounding factors. An unorthodox presentation format required some players to move simultaneously, and although others moved sequentially, their moves were timed, and a failure to move within each 10-second window caused the move to pass on to the co-player, in effect treating non-responses as cooperative GO moves and imposing considerable psychological pressure on players to move quickly. At least some—perhaps

many—of the defections in this experiment may represent panic moves, rather than carefully considered decisions to defect.

Extending their previous experiment, Cox and James (2015) conducted another complex Centipede study that included one of McKelvey and Palfrey's (1992) original Centipede games together with four other games conditions that differed in stake size, payoffs to non-takers (Take-it-or-leave-it game versus standard Centipede game), time pressure imposed, and presentation format (clock versus tree format). Again, Take-it-or-leave-it payoff functions led to earlier defection. Similarly, Krockow, Pulford and Colman (2015) reported a carefully controlled comparison of exponential Centipede games with more competitive payoff functions, including Take-it-or-leave-it game versions. They reported significantly lower cooperation levels than in a standard exponential game, but they also found that the combination of different competitive game aspects (e.g., Take-it-or-leave-it payoff function with zero payoffs at final terminal node) resulted in a weakening of the aspects' independent deterrent effects, demonstrating that the effects do not combine synergistically or even additively.

Another relevant study in the context of Take-it-or-leave it Centipede games is McIntosh, Shogren, and Moravec's (2009) investigation of competitive Centipede tournaments. Across two experiments, subjects completed five Centipede games using the strategy method. Because the strategy method requires players to specify in advance how they would act in every situation that could arise in the game, it is possible for a researcher to match any two strategies in a virtual game to determine what the outcome of the game would be. In this experiment, each subject's strategy was matched with every other subject's strategy twice, so that player roles could be reversed the second time around. All games had identical payoff trees but different rules on how to convert payoff points received in the game into actual cash earnings. Most conversion rules were based on linear functions: the total

number of payoff points earned in the experiment was multiplied by a fixed rate of exchange. However, both experiments also included one competitive treatment condition each in which the subjects' strategies were entered into tournaments, and monetary rewards were determined based on relative ranking schemes.

In the tournament of Experiment 1, the strategies were ranked according to the total number of payoff points earned. In the tournament of Experiment 2, "tallies" were awarded to the "winner" of each game, essentially turning the original Centipede game into a constant-sum, Take-it-or-leave-it game. The subject with the highest number of tallies overall, received the highest financial reward. In Experiment 1, only 11.9% of tournament games ended at the first decision node, and no significant differences were found between the tournament treatment condition and the treatments using other (less competitive) conversion rules. After adding the tallies in Experiment 2, the tournament treatment yielded an exit percentage of 38% at Node 1 that differed significantly from the four treatments with less competitive monetary conversion rules. These results indicate that the binary Take-it-or-leave-it incentive structure significantly decreases cooperation levels.

Risk cost and payoff asymmetry. Horng and Chou (2012) examined another aspect of the payoff function, namely the *risk cost* associated with each GO move. Risk cost is the loss of payoff resulting from a GO move in the event that the co-player defects at the immediately following decision node. In the high risk cost treatment condition, each cooperative GO move led to a decrease of the prospective personal payoff of 90%; in the medium risk cost condition, the decrease was 50%; and in the low risk cost condition, the decrease was 20%. The results showed significant differences between these three conditions, with the high risk cost condition yielding earlier defection than the other two. An interaction was found between risk cost and overall stake size, a larger effect of risk cost occurring in games with high stakes than in games with low stakes.

High risk cost, as defined by Horng and Chou (2012), is almost invariably associated with payoff asymmetry between players. When the cost of a GO move to a player is increased, the co-player's share of the pot has to be increased proportionately to maintain the payoff function. Murphy et al. (2006) manipulated payoff asymmetries at the terminal nodes in exponential Centipede games presented in a format as unorthodox as Cox and James's (2012), characterized by simultaneous moves, non-discrete decision nodes and a large number of players. They reported that larger differences between payoffs induced more competitive play and led to significantly earlier defection.

Pulford et al. (2016) compared three types of eight-move linear Centipede games of varying payoff symmetry. In the standard version, the payoff difference between players remained constant throughout the game. In the other two versions, the differences either decreased or increased with every decision node that was passed. The results showed highest cooperation levels in the decreasing-difference game, probably due, at least in part, to inequality aversion, because cooperation in this game had the effect of reducing inequalities between players' payoffs. Similarly, Miniadis (2008) manipulated the payoffs at the final terminal node of their exponential Centipede games, and found that lower payoff inequalities significantly increased cooperation compared to their control condition.

Focal points. The standard Centipede game with its payoff function following a regular and logical mathematical pattern lacks useful focal points as delineated by Schelling (1960). If any terminal node is made more salient (or focal) by breaking the previous payoff pattern, this should focus the players' attention on the anomalous node, improve predictions about the likely decisions at the node in question, and subsequently enhance BI reasoning. An unpublished study by Atiker, Neilson, and Price (2011) directly manipulated payoff functions to introduce either early or late focal points to their ten-move Centipede games. Both types of focal points increased the frequency of Nash equilibrium play, and the early focal points (at

Nodes 3 and 4) had a particularly large effect. Using the strategy method, these researchers found 34.7% of players in role A to choose defection at Node 1 as opposed to 4% in their standard Centipede condition.

The focal point theory also extends to findings regarding the influence of zero payoffs at the game's final end (e.g., Krockow et al., 2015; Rapoport et al., 2003). It is possible that equal payoffs of 0 at the ultimate terminal node appear salient to the players, because they break the pattern of the rest of the payoff function. Consequently, players may be better able to predict decision-making at the penultimate node, which in turn could have the effect of kick-starting BI reasoning. This interpretation is supported by Krockow et al.'s (2015) comparison of exponential Centipede games with either standard payoffs at the end or zero payoffs, demonstrating that the zero-end type results in significantly earlier game exits.

Incentives. A number of investigations have shown that financial incentives tend to reduce the variance in decision makers' behaviour and more generally bring decisions closer to the normative prescriptions of decision theory and game theory, especially for decisions of intermediate difficulty (Camerer & Hogarth, 1999; Hertwig, & Ortmann 2001). Several studies have manipulated stake size to investigate the effects of financial incentives on decision making in Centipede games. McKelvey and Palfrey (1992) included a high-payoff treatment condition in their experiment in which payoffs were quadrupled relative to the control condition. Overall, however, their stakes were not very large—in the high-payoff condition, the maximum individual payoff was \$75.00, and the average actually received was only \$41.50. Rapoport et al. (2003) used much higher incentives in a nine-move exponential Centipede game, with a maximum individual payoff of \$2,560 dangling from the Centipede game's front leg (this was a game with zero payoffs in the last terminal node). Compared to their lower-stakes treatment condition, the high-stakes condition yielded significantly lower levels of cooperation. Over 60 rounds of the game, as many as 39% of high-stakes games

ended at the first decision node, and only 17% continued beyond the third. An unpublished paper by Nachbar (2014) reported an experiment with high stakes, as in Rapoport et al.'s study. In a fifteen-move Centipede game, Nachbar also found a high proportion of defections at the first decision node.

These high-stakes games were all multi-player Centipede games (three and five players respectively) with an unusually high payoff asymmetry between players. Rapoport et al.'s (2003) high-stakes condition had a payoff ratio of 10:1:1 (the defecting player received \$10 whereas the “losers” received \$1 each) at every terminal node, compared to 4:1 in the two-player high-payoff game used by McKelvey and Palfrey (1992). Furthermore, every GO move in the high-stakes condition was associated with high risk cost—an 80% decrease in personal payoff at the next terminal node—and, because it was a three-player game, every player had to wait for two co-players to move before being able to move again, adding to the risk of cooperation. In the light of Horng and Chou's (2012) later findings of the effects of risk cost on decision making in the Centipede game, this suggests that Rapoport et al.'s study may be confounded. Whereas high stakes undoubtedly encouraged early defection, it is impossible to disentangle the relative effects of stake size and risk cost, both of which were exceptionally high in the high-stakes condition. Further research by Farina and Sbriglia (2008a, 2008b) corroborated the findings on the importance of stake size. Comparing Centipede games with two different, moderately high stake sizes and moderate risk costs, the authors reported lower cooperation levels in the game condition with higher stakes.

Incomplete information. The vast majority of experimental Centipede research has focused on games with complete information. The first study to introduce an element of incomplete information was reported by Cox and James (2012). In their experiment, the initial payoffs at the first terminal node were randomly drawn from a uniform distribution from 0.01 to 10.00. Both players were informed about their own draw as well as the general

rule governing payoff increases from node to node, but each player was ignorant of the co-player's initial payoff. Unfortunately, Cox and James did not include a control group with complete information, hence the magnitude of the effect of incomplete information on Centipede play is unknown.

In a study aiming to achieve greater applicability to real-life decision situations with uncertain prospects, Krockow, Takezawa, Pulford, Colman, and Kita (2016) carefully manipulated the payoff information provided to the subjects. Their study introduced two game conditions with incomplete payoff information, providing either absolute information (own payoff information) or relative information only. Results included cross-cultural data from Japanese and UK subjects, and the amount of payoff information was found to affect decision making in both countries. In Japan, both treatment conditions with incomplete information yielded significantly higher cooperation levels than the control with complete information. In the UK, only the condition with absolute payoff information produced significantly higher cooperativeness. The authors could not fully interpret these results, but it appears that in Centipede games with incomplete information, expectations about the stake size may guide decision making, with lower expectations resulting in higher cooperation levels.

Decision space. In order to overcome the limitations of the alternating decision structure of the Centipede game, Murphy et al. (2006) introduced a version without discrete decision nodes. In the standard Centipede game, the inequality of payoffs between the two players at any terminal node leads to an inherent asymmetry between player roles. Consequently, in games with even numbers of moves, Player A has better payoff prospects and—depending on the payoff function—this advantage can be substantial. An iterated *real-time trust game* (RTTG) introduced by Murphy et al. involved multiple players (either three or seven in their experiment), who decided when to stop a game within a continuous time

frame of 45 seconds. No player was assigned any particular role, and consequently any player could exit at any time. With time elapsing, the total payoff to all players increased in line with the payoff function approximating an exponential Centipede game. The player stopping the game (the “winner”) received the lion’s share of the payoff associated with the stop time, and all other players (the “losers”) received equal but smaller payoffs. If no player decided to STOP before the natural end, then all subjects received zero payoffs (this is equivalent to zero payoffs in the final terminal node of a conventional Centipede game).

The RTTG resembles a Centipede game because of its payoff function, but it lacks the discrete sequential structure that, in standard Centipede games, enables players to signal trust and cooperation by actively choosing GO moves rather than by doing nothing. This turns the RTTG into a highly competitive game, especially with many players and high payoff ratios (much greater payoffs to winners than losers). Experimental results showed that, under these extreme conditions, cooperation dropped rapidly towards the game-theoretic subgame-perfect equilibrium solution, and the experimenters even decided to abort one testing session prematurely because of “clear signs of irritation in some of the subjects” (Murphy et al., 2006, p. 158).

A similar procedure was used by Cox and James (2012) with Centipede games presented either in the classic game tree format or in a “clock format”. The clock format translated the traditional game tree of a 10-move Take-it-or-leave-it Centipede game into a 10-second time frame, with each tick of a clock indicating the next move. As in the RTTG of Murphy et al. (2006), only STOP moves required any action by the players, non-action functioning as GO, and payoffs dropped to zero if no player terminated the game within the given time frame. The payoff function followed the usual pattern of a Take-it-or-leave-it Centipede game (with zero payoffs at the end), the player stopping the game receiving the entire payoff pot and the co-player nothing. The authors compared decision making across

four treatment conditions, pairing clock Centipede games and standard tree Centipede games with either simultaneous moves or sequential moves. Results showed that subjects presented with a game in tree format defected later than those given the clock format, and that games ended later in sequential-move games than in simultaneous move games. Regardless of the initial levels of cooperation, players across all game conditions showed high learning rates and converged to equilibrium play after several repeated rounds. In the condition combining simultaneous move structure and clock format, near-perfect equilibrium play was reached after only three rounds.

These results stand out from the relatively high levels of cooperation and mixed learning effects found in experiments with orthodox Centipede games. It is difficult to pinpoint the precise reason for this, because Cox and James (2012) used a complex experimental design incorporating several unusual features at once, including incomplete payoff information, a Take-it-or-leave-it payoff function, zero payoffs for all if no player defected, and clock timing. Furthermore, follow-up research by the same authors (Cox & James, 2015) investigating four-move Centipede games produced contradictory results. In contrast to their earlier study, game versions with time pressure and clock format did not yield lower cooperation levels than the control condition. Additional research with carefully manipulated control conditions is necessary to clarify the previous contradictory results.

Number of players. The Centipede game was originally envisaged as a two-player game (Rosenthal, 1981), and the majority of experimental studies, starting with McKelvey and Palfrey (1992), have used two-player games. A small number have investigated multi-player Centipede games. In the most common multi-player version, three players take turns deciding between the usual STOP and GO moves in an exponential game with nine decision nodes. A player who defects receives a larger payoff than the co-players, who typically receive the same smaller payoff as each other, and at the final terminal node all three receive

zero payoffs. This three-player version, first studied by Parco, Rapoport, and Stein (2002) and Rapoport et al. (2003), yielded very different results from previous Centipede studies, but only when combined with very high stakes. The low-stakes version elicited remarkably similar behaviour to McKelvey and Palfrey's (1992) six-move, two-player game. Only 2.5% of the low-stakes three-player games were in line with the equilibrium solution (compared to 0.7% in the two-player game) and both games produced the same noticeable decision pattern, with relative frequencies of STOP moves increasing from one decision node to another.

In an unpublished study using five-player, high-stakes Centipede games, Nachbar (2014) reported high defection rates at the first decision node (0.363) but found less evidence for learning across game rounds and a higher number of consistent cooperators than in Rapoport et al.'s (2003) high-stakes three-player experiment. Murphy et al.'s (2006) experiment, using a continuous-move version of the Centipede game, was the only study directly investigating the effects of player numbers. The results showed that increasing the number of players from three to seven led to significantly earlier defection. Future research should continue to investigate the effects of player numbers on decision making, particularly the differences between standard two-player games and multi-player versions. Any direct comparison will need to control for payoff function variations (including risk cost and payoff asymmetry) and game length.

Game length. Any Centipede game, irrespective of its payoff function, can be extended indefinitely by adding decision nodes and associated terminal nodes according to the appropriate payoff function rule. Game length appears to be a seriously under-researched independent variable. Experimental Centipede games have all been comparatively short, with numbers of decision nodes ranging from 3 to 12. Nachbar's (2014) unpublished study reported results from a game with 15 decision nodes, but this was a five-player game, and 15 decision nodes could be considered the minimum length for a player group of that size,

because no player can make more than three moves. Only McKelvey and Palfrey (1992) and Fey et al. (1996) have compared behaviour in games of different lengths directly, and the differences that they examined were small: four versus six decision nodes (McKelvey & Palfrey) and six versus ten decision nodes (Fey et al.).

Our own retrospective analysis of variance of McKelvey and Palfrey's (1992) dataset reveals a significant difference between the mean exit proportions 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 medium effect size, whereas their low-stake four-move and low-stake six-move games did not differ significantly. Hence, although there was evidence for differences between games of different lengths in McKelvey and Palfrey's study, it is difficult to disentangle the respective effects of game length and stake size. Further research needs to be done to arrive at a better understanding of the effects of game length.

Number of rounds. Increasing experience with a game can have an important impact on decision making (Ponti, 2000). Some studies of the Centipede game have varied the numbers of repetitions or rounds of the game, ranging from one (Bornstein et al., 2004; Levitt, List, & Sadoff, 2011; Palacios-Huerta & Volij, 2009) to many rounds. Most experiments with multiple rounds have revealed small learning effects: McKelvey and Palfrey (1992), Fey et al. (1996), and Pulford, Colman, Lawrence, and Krockow (2016) all reported slightly earlier defection in later than earlier rounds of the game. Thiele (2012) found decreasing cooperation over three rounds of Centipede games played with the same co-player. However, when the co-player was changed on the fourth round, cooperation spiked upward once more before decreasing again over the following game repetitions with the second co-player, suggesting that repeated games with the same co-player may be treated by

players as a supergame (one large game consisting of several iterations of the basic Centipede game), thus evoking different learning patterns.

Nagel and Tang (1998) investigated learning patterns over 100 rounds of a Centipede game and found the emergence of some inflexible strategies that were not usually in line with the game-theoretic solution. It is unwise to generalize these findings, because Nagel and Tang presented the game to the players in reduced normal form, as an abstract payoff matrix rather than a game tree, and subjects merely indicated their preferred stopping nodes. This had the effect of turning an essentially dynamic, sequential-move game into a one-shot simultaneous-move game. Furthermore, the highly complex payoff matrix may have been poorly understood by some subjects.

Rapoport et al. (2003), using a conventionally presented three-player exponential Centipede game, found convergence towards the subgame-perfect equilibrium after 60 rounds of play, but this effect occurred only in their extremely high-stakes experiment and not in their lower-stakes experiment. The previously reviewed studies of continuous-move and simultaneous-move games (Cox & James, 2012; Murphy et al., 2006) also reported evidence for learning across the number of game rounds, with rapid convergence towards subgame-perfect equilibrium play, irrespective of initial cooperation levels. An investigation by Huck and Jehiel (2004) of Take-it-or-leave-it games in which players were provided with varying amounts of information about their co-players' previous decisions suggested that the availability of accurate information about the co-player's choices in the most recent game rounds of the experiment encouraged early defection.

Summary of Game Variables

Taken together, the results on game variables suggest that payoff function variations and incentives affect behaviour significantly, but more research is required to understand the separate and joint effects of these variables. Players are highly sensitive to variations in

payoff functions: they exhibit higher levels of cooperation in symmetric, low risk cost payoff structures that provide opportunities for social gains. There is some evidence that high stake sizes lead to earlier defection in three-person, high risk cost Centipede games, but more research is needed to investigate the effects of incentives in standard two-player games when effects of other game variables are controlled. It seems reasonable to infer from the existing evidence that high stakes, high risk costs, and payoff asymmetry are likely to accelerate learning effects and convergence towards subgame-perfect equilibrium play over repeated rounds of the game, but additional research is necessary before these effects are firmly established.

One factor that has received insufficient attention to allow any firm conclusions to be drawn is game length (number of decision nodes). Another factor of potential importance that has not received any attention at all from researchers is sample size per testing session. When studying interactive behaviour across repeated rounds with anonymous and random re-pairing, the number of subjects in a testing session needs to be sufficiently large to avoid supergame effects—treating separate games as parts of a single game—and reciprocity between rounds. The studies of Rapoport et al. (2003) and Murphy et al. (2006), reporting some of the highest learning rates in the literature, used multi-player designs with only 15 and 21 subjects per testing session respectively. In Murphy et al.'s seven-player condition, for example, only three games were played at the same time, and re-matching of the same players must have occurred frequently.

Situational Variables

Situational variables are aspects of the social or experimental environment in which the task is performed that may influence players' behaviour. Comparatively little research on the Centipede game has investigated the influence of such variables, even though they may

have important implications for decision making. In the paragraphs that follow, we review four main factors studied in this area to date.

Individual versus group decision making. A substantial body of evidence has accumulated in support of the *interindividual–intergroup discontinuity effect*, according to which interactions between individuals tend to be more cooperative than interactions between groups, and this is usually attributed to greater fear and greed in intergroup relative to interindividual interactions (Wildschut et al., 2003). Bornstein et al. (2004) compared individual and group play in six-move constant-sum and linear increasing Centipede games. In the group condition, three subjects conferred before making a joint decision at each decision node. In addition to the quantitative assessment of exit nodes, the group discussions were recorded for additional qualitative analysis. In line with the interindividual–intergroup discontinuity effect, the main finding was that group players defected significantly earlier than individuals in both types of games. In the linear Centipede game, none of the three groups reaching the final decision node chose the cooperative GO option, whereas in the individual condition, three out of four players who reached that point decided altruistically to cooperate.

Bornstein et al. (2004) offered several explanations for these findings, one of which was that groups appeared to be less prosocial than individuals. This inference was backed up by the taped discussions, in which a single competitive individual could persuade the group to defect more easily than a cooperative individual could persuade the group to cooperate. Based on these findings, the authors suggested that group players may resemble the rational agents assumed by classical game theory more closely than individuals do. An alternative explanation is that due to ingroup–outgroup biases, group players may feel more strongly about the payoffs of fellow ingroup members. With the aim of maximizing ingroup payoffs

and beating the outgroup, they might defect earlier than in the individual player condition. The following subsection includes a more detailed discussion of ingroup–outgroup biases.

Important decisions in everyday life are increasingly often made not by individuals but by groups, and in some cases—two teams of lawyers making alternating proposals in an effort to negotiate a legal settlement, two boards of directors of commercial companies making alternating suggestions about a potential arrangement of mutual benefit, a trade union and an employers’ executive committee taking turns suggesting an acceptable settlement to an industrial dispute, and so on—reciprocal turn-taking of the Centipede type appears relevant. The potential value of further studies of group decision making in Centipede games therefore seems high. Furthermore, as Bornstein et al. (2004) used a one-shot Centipede game, replications using repeated games may provide interesting insights into individual versus group learning processes.

Ingroup and outgroup interactions. Le Coq, Tremewan, and Wagner (2015) compared six-move exponential Centipede games played between individual members of the same social group (ingroup interactions) and members of different social groups (outgroup interactions). The study was theoretically grounded in a large body of research suggesting that perceptions of group identity can produce favourable attitudes towards ingroup members and dismissive attitudes towards outgroup members (for an overview, see Postmes & Branscombe, 2010), thereby presumably affecting behaviour and decision making in relevant social contexts. In line with previous research, the authors hypothesized that ingroup interactions would produce higher levels of mutual cooperation, but they were surprised to find no significant difference: outgroup decisions were more cooperative, although the difference was not statistically significant. Le Coq et al. suggested that subjects may have perceived their fellow ingroup members to be more similar, and this assumption of ingroup similarity could have led to a higher certainty about their co-players’ likely exit nodes. The

outgroup condition, on the other hand, provided fewer social clues about the co-players' probable strategies, and players in that condition may consequently have engaged in more exploratory play to test for the outgroup members' willingness to cooperate at different stages of the game, leading (possibly) to slightly increased levels of cooperation.

These findings should be treated with caution. The investigators used Selten's (1967) strategy method, an experimental procedure that eliminates the sequential interaction between players that is inherent in the standard procedure. Players were merely asked to indicate whether they would choose STOP or GO at each decision node if the opportunity were to arise. To determine the subjects' respective payoffs, the strategy vectors of two randomly selected players were pitted against each other. This method obviously fails to capture the dynamic essence of the Centipede game.

Effects of extreme players. Murphy, Rapoport, and Parco (2004) studied the influence of extreme player types on overall cooperation levels within groups of players. By adding zero, three, or six computer players with programmed strategies (either unconditional cooperators or unconditional defectors) to their testing sessions of 21, 18, or 15 human players, they investigated whether the sample composition could affect the general patterns of decision making over 90 rounds of a three-player, nine-move exponential Centipede game. The results showed that the addition of unconditionally cooperative programmed co-players increased the cooperation of the human players significantly, leading to later (human) defection than was observed in a control group without programmed co-players. In contrast, the inclusion of unconditionally defecting co-players had no significant effect on the behaviour of human players. The authors suggested that this could be explained by the existence of "hard-core cooperators" who showed very high levels of cooperation independent of their co-players' choices, and that other less inflexible players seemed willing, nonetheless, to ignore the highly non-cooperative behaviour of a few of their co-players,

presumably attributing it to greed, stupidity, or malice. The authors concluded that natural predispositions to cooperation have an important influence on decision making in the Centipede game that cannot be reversed by the competitive play of a minority of co-players. These findings corroborate McKelvey and Palfrey's (1992) identification of diehard altruistic player types and offer important insights into group dynamics within a given testing session. They also highlight the importance of large sample sizes in order to overcome potentially distorting effects of a few highly cooperative players.

Interpersonal control. Previous research suggested that the level of interpersonal control in combination with the perceived "barrier to success" might have an influence on decision making in the Centipede game. Sheldon and Fishbach (2011) studied decisions of subjects in the role of Player A—arguably the role with higher interpersonal control in the Centipede game, because it empowers the first—and in certain cases the only—decision. The authors manipulated the perceived barrier to success in the game by asking subjects to think about risk in the task (strong barrier to success) or about security in the task (weak barrier to success). The human Player As were subsequently paired with computer players and completed one Centipede game each. Findings showed that subjects in whom expectations of strong barriers to success had been induced cooperated significantly more frequently than those with the opposite induction. The authors suggested that subjects in the strong barrier condition increased their cooperation to counteract the anticipated difficulties in the task and the temptation to defect. They further argued that this was possible only because of their induced perception of control vis-à-vis their co-players.

In a study of a three-move exponential Centipede game, El-Gamal, McKelvey, and Palfrey (1993) found support for the importance of players' past experience in the game. Their sequential econometric model suggested that subjects learn about the population within a given testing session and adapt their play on the basis of previous experience. These results

were extended by three as-yet unpublished studies manipulating the amount of information available to players about their co-players' history of decision making (Gamba & Regner, 2015; Huck & Jehiel, 2004; Maniadis, 2008).

In a complex experiment using a nine-move Take-it-or-leave-it game, Huck and Jehiel (2004) found that subjects used both their own past experience and public information—if available—to inform their decisions. The use of public information was particularly influential in conditions in which players were provided with detailed statistics (relative frequencies of GO choices at specific decision nodes, aggregated over the most recent games), and this tended to lead to a continuous decrease in cooperation across 50 rounds of play. Because this study used a competitive Take-it-or-leave-it game, it would be imprudent to generalize the findings to other types of Centipede games. However, the experiment does provide evidence for the influence of players' reputations on their co-players' decision making.

In a related study conducted as part of an unpublished PhD thesis, Maniadis (2008) investigated the effects of varying amounts of aggregate information about the previous game outcomes (no information, full information and partial information about other player group only) on decision making in two different Centipede games. In line with Huck and Jehiel's (2004) results, information about previous play decreased cooperation levels. Interestingly, Gamba and Regner (2015) obtained slightly different results in a similar study. The authors manipulated the type of information about the co-player's behaviour (personal information about own game outcome only versus public information about all game outcomes from previous round) while comparing results across different elicitation methods in the games (direct response method versus strategy method).

Gamba and Regner (2015) also measured *social value orientation* (SVO), a psychological concept introduced by Messick and McClintock (1968) denoting a person's

preference about how to allocate a divisible resource such as money between self and another person. In Gamba and Regner's experiment, SVO was assessed using a combination of questionnaire data from an SVO scale and behavioural data from a simple trust game. The data from the two-move sequential trust game, characterized by a choice dilemma between selfish and cooperative strategies similar to the Centipede game, was used to determine a threshold for categorising the continuous scores derived from the SVO questionnaire. Subjects were subsequently categorized as either *proselfs* (people who are motivated solely or predominantly to maximize their own payoffs) or *prosocials* (people who are motivated to maximize not only their own payoffs but also the payoffs of the co-player).

The authors reported that *proselfs* cooperated more frequently in games with public information (particularly when combined with the strategy method) compared to games with personal information only. This was explained by the fact that the additional information about choices of all players of opposite participant role (rather than just of the own co-player) led them to adapt their initially non-cooperative strategies in order to increase their own payoffs. These findings suggest that individual differences could play an important role when it comes to information processing of co-players' previous choices, with *proselfs* being more flexible in their strategies than *prosocials*. Overall, additional public information led to an increase in cooperation, rather than a decrease as reported by Huck and Jehiel (2004) and by Maniadis (2004)—this could be attributed to the linearly increasing payoff function of the Centipede game used in their study, where cooperation involves greater risk than in the games with exponentially increasing payoff functions that were used in earlier studies. For a more detailed discussion on risk-cost associated with different types of payoff functions, refer back to the section on Game Variables.

Using a slightly different approach to providing information about the co-player, Farina and Sbriglia (2008a; 2008b) investigated the effects of knowledge about the co-

players' strategic profile in a trust game on decision making in the Centipede game. Subjects completed a two-stage trust game using the strategy method and then played two Centipede games. Before engaging in the Centipede game, the players were informed about their co-players' choices in the trust game, identifying them as selfish, altruistic, or reciprocating individuals. Again, information about choices in the trust game decreased cooperation in the Centipede game. The authors attributed this to very early game exits by homogenous pairings of selfish individuals.

Whereas the above studies suggested that public information about a player's history in games with random player matching led to a decrease in cooperation, Pulford, Colman, Lawrence, and Krockow (2016) found the opposite effect for fixed player matching (repeated games played with the same co-player) over 20 rounds of eight-move linear Centipede games. The authors reported significantly higher levels of cooperation with fixed matching compared to their random matching control conditions. These findings were interpreted to indicate the effect of reputation-management in the service of reciprocity across repeated games with the same co-player.

Wealth differences. It seems reasonable to expect different levels of income and overall wealth among research subjects to influence their behaviour in any incentivized experiment. Furthermore, the knowledge of the co-player's wealth and likely attitudes towards the incentives may also have an impact on behaviour. In a six-move exponential Centipede game, Basu, Mitra, and Gupta (2013) investigated whether public information about the co-player's wealth (categorized as low, middle, or high income) would have an impact on decision making over five rounds of play. Using a within-subjects design, they manipulated the pairings of their subjects: players were paired randomly in one treatment condition, with co-players from the same income group in a second, and with co-players from a different income group in a third condition. In the latter two conditions, subjects were

informed about their co-players' respective income group before the start of the game.

Comparing patterns of decision making for the different treatment conditions, Basu et al. reported that the number of defecting moves differed significantly across the three treatment conditions. Although the report is not entirely clear, it appears that the highest level of cooperation occurred when players were randomly paired without information about the co-player's income group, and the lowest level when they were paired with co-players from a different income group. The authors interpreted this to indicate that wealth information had a significant impact on decision making in the game.

The design and data analysis of the experiment reported by Basu et al. (2013) suffers from several shortcomings, including a small sample size and possible order effects (all subjects completed the treatment conditions in the same sequential order). The within-subjects design that was used may not be ideally suited to the study of experimental games. Carryover effects are likely to occur, and because the outcome of any one game depends partly on the co-player's decisions, the comparison of a player's scores across conditions is problematic. Also, it is questionable whether effects of wealth information on decision making can be attributed to financial or economic factors per se. Rather, knowledge of a co-player's income group is likely to contribute to social identity effects by eliciting either ingroup or outgroup attitudes and behaviour, as suggested by Le Coq et al. (2015). This explanation could be particularly powerful in countries such as India in which different income levels are associated with different social groups or castes. Basu et al.'s subjects were all recruited from Jadavpur University in Kolkata, India. Future research could build on Basu et al.'s highly suggestive study by extending it and introducing better experimental control in a between-subjects design with a larger number of players and, perhaps, questionnaire measures of relevant socio-cultural attitudes.

Summary of Situational Variables

Although the empirical base of these findings is relatively small, a number of situational variables have been found to affect reciprocal cooperation in repeated interactions. Group decision makers appear to exhibit lower levels of cooperation than individual players in Centipede games. This could be due to decreased levels of prosociality in groups or to ingroup–outgroup biases. The presence of a minority of highly cooperative and altruistic players in repeated rounds of a Centipede game encourages cooperation in the rest of the player sample present at the same testing session, and this has important implications for experimental methodology, including the sizes of testing sessions and matching algorithms. Additional factors, such as social identity and players' perceived wealth levels may also influence decision making in Centipede games but these require further investigation.

Individual Difference Variables

In the context of this review, individual difference variables are more or less stable psychological or behavioural differences between players (Vinacke, 1969). Only a small number of individual differences have been systematically investigated in relation to reciprocal cooperation in Centipede games.

Cognitive ability. Much discussion about the Centipede game has focused on the reasoning abilities involved in inferring the game-theoretic solution. The deliberate and self-conscious application of BI requires stepwise reasoning and high concentration on the task (Camerer & Fehr, 2006; Colman, 2003; Dulleck & Oechssler, 1997), and this may pose a considerable challenge to many research subjects (typically, undergraduate students). Gerber and Wichardt (2010) therefore designed an experiment to test the iterative reasoning abilities of student subjects over ten rounds of an eight-move linear Centipede game. The researchers introduced two treatment conditions, offering players one of two different tools designed to delay game termination and increase cooperation. In the first condition, subjects could decide whether to buy insurance that would top up their payoffs in the event of a co-players'

defection. In the second condition, players could offer their co-players bonus payments, paid for out of their own payoffs, as a reward for not defecting. The researchers argued that both tools ought to be chosen by rational players, according to game-theoretic analysis, but that the insurance tool requires stepwise reasoning to assess its benefits, taking into account its signalling value (buying insurance signals to co-players that one no longer fears defection) whereas the bonus tool was easier to comprehend. This difference was reflected in the results: the bonus option was chosen frequently (in 154 instances out of 200) and the insurance tool comparatively rarely (in 53 instances out of 200). The researchers interpreted their results as “consistent with subjects using only a limited degree of iterated reasoning” (p. 135), but the evidence seems rather indirect. Furthermore, a cross-cultural study with an almost identical game design reported by Krockow, Takezawa, Pulford, Colman, Smithers, Kita, and Nakawake (2016), comparing decision making in Japanese and European (mostly UK) subjects, found that differences between the use of the two tools were no longer significant when instruction materials and experimental software were improved. This study’s instructions included detailed explanations of all possible payoff scenarios depending on tool purchase, followed by a comprehension test. Furthermore, the computer screens displayed updated payoff matrices of the games for each round, taking into account how many players had opted for a tool. This suggests that Gerber and Wichardt’s original findings may have been due mainly to limitations in the overall cognitive capacities of subjects as opposed to specific difficulties with iterated reasoning.

Palacios-Huerta and Volij (2009) conducted a study to test for a direct effect of BI reasoning skills on decision making in a one-shot, six-move exponential Centipede game. They sampled a group of expert chess players, including internationally renowned chess grandmasters, who were assumed to be accustomed to using iterative reasoning in chess games. The study, which used a high-stakes version of McKelvey and Palfrey’s (1992) six-

move exponential Centipede game, consisted of a field experiment and follow-up laboratory sessions, investigating interactions between chess players and undergraduate students. Among chess experts, 73% of all field Centipedes conformed to the game-theoretic solution and stopped at the first decision node. Furthermore, whenever Player A was a grandmaster, 100% of games stopped at the first decision node. In comparison, McKelvey and Palfrey's low-stakes six-move game ended at the first node in less than 1% of all cases. Interestingly, the pattern of early defection was not replicated when chess players were matched with students of presumably lesser cognitive ability in the laboratory; the percentage of games stopping at the first decision node was halved. Taken together, these findings suggest a strong connection between iterative reasoning ability and decision making in the Centipede game. Furthermore, the fact that chess players behaved more cooperatively when paired with students, whose rationality they presumably doubted, lends support to the theoretical prediction that common knowledge of rationality is a key prerequisite for equilibrium play.

These results on the importance of common knowledge of rationality are called into question by an as-yet unpublished study of Wang (2015), who assessed their subjects' predictions of co-players' strategies and examined whether the subjects' choices represented the best reply to their co-player's anticipated exit move. The results indicated substantial differences between actual choices and best reply as based on the players' own beliefs. This suggests that the beliefs about the co-player (including common knowledge of rationality) may not be the crucial factor informing decision making. However, it is also important to note that Wang assessed the subjects' beliefs after they had already completed the game component of the experiment. It is possible that at the time of decision making they did not actually engage in careful considerations about their co-players' likely strategies, and this could explain the divergence between actual game choices and theoretically best replies.

Overall, Palacios-Huerta and Volij's (2009) results from their experiment on chess players are among the closest to the subgame-perfect equilibrium ever reported (see Figures 3 and 4), and their findings with chess grandmasters in the role of Player A showed 100% subgame-perfect play. Levitt et al. (2011) attempted to replicate these findings with a similar experimental design, using the same one-shot, six-move exponential Centipede game and a comparable sample of chess players, including grandmasters. Additionally, their subjects completed two rounds of the Race to 100 game, a game that also requires iterated reasoning but whose constant-sum, winner-take-all payoff function precludes any social gains and provides no reason for cooperating. In the Race to 100 game, two players take turns choosing whole numbers from a pre-defined set, for example $\{1, 2, \dots, 9\}$, aiming to arrive at a sum of 100, with the player who chooses the last number winning the race. This game can be viewed as a more direct measure of BI reasoning skills than an increasing-sum Centipede game, where other-regarding preferences (a concern for the other player's payoff or for the team payoff) could affect decision making.

Levitt et al. (2011) failed comprehensively to replicate the findings of Palacios-Huerta and Volij (2009). Their chess players were as cooperative as a typical student sample, with only 3.9% of games stopping at the first decision node. Also, contrary to the earlier experiment, not a single chess grandmaster in the role of Player A opted for immediate defection. The chess players solved the BI problem frequently in the Race to 100 game, but none of those who showed perfect BI reasoning in Race to 100 defected at the first opportunity in the Centipede game. These findings indicate that advanced cognitive abilities and BI reasoning skills may not be the decisive determinants of decision making in Centipede games.

In an as-yet unpublished study, Baghestanian and Frey (2014) used a similar approach to determine the importance of cognitive abilities on decision making in the Centipede game.

They sampled professional players of the complex strategic board game “Go” and compared their choices across four different games: normal-form Centipede game, Traveller’s dilemma, Kreps game, and Matching Pennies game, the first two of which are characterized by inefficient equilibrium solutions. They further measured strategic reasoning skills by assessing the subjects’ Go Elo scores (numerical ratings of the relative skills of players in competitive games, originally chess) and analytic reasoning skills with the help of the Frederick cognitive reflection test (CRT). Subjects were found to deviate from the Nash equilibria in Centipede games and Traveller’s dilemmas but not in the other two, suggesting that those deviations were unlikely to have been caused by a lack of cognitive ability. However, decision making in those two games correlated with the two different reasoning measures, with higher Elo scores related to lower cooperation levels and higher CRT scores related to higher cooperation levels. These findings suggest that different types of reasoning may affect decision making in the Centipede game. Given that the findings of Levitt et al. (2011) appear to contradict those of Palacios-Huerta and Volij (2009), and in view of the inconclusive findings of Baghestanian and Frey (2014), additional experiments are called for.

Other-regarding preferences. Numerous studies across several areas of research in experimental games have indicated that human decision makers are not concerned solely with their own payoffs but appear also to be motivated by other-regarding preferences. McKelvey and Palfrey (1992) reported that 8% of their sample were altruists who cooperated at every opportunity and similar proportions have been observed in subsequent research (e.g., Rapoport et al., 2003; Murphy et al., 2004). Experiments manipulating payoff structure and comparing Centipede games with and without social gains have found significantly higher cooperation rates in the former (e.g., Bornstein et al., 2004; Fey et al., 1996; Kawagoe & Takizawa, 2008; Levitt et al., 2011). One factor, well documented across a range of experimental games and in other areas of psychology, that can help to explain this finding is

inequality aversion (Fehr & Schmidt, 1999; Hatfield, Walster, & Berscheid, 1978). Perhaps even more important are collective rationality and prosocial preferences, which appear to play important roles in Centipede games. A substantial proportion of players seem to be driven by the motivation to increase the joint payoff of the player pair. Colman, Pulford, and Rose (2008a, 2008b) and Colman, Pulford, and Lawrence (2014) have provided strong experimental evidence for the importance of other-regarding preferences, especially collective rationality, in other types of games.

To clarify different underlying motivations in experimental games, including the Centipede game, the psychological concept of social value orientation (SVO) is useful and interesting. Viewed as an individual difference trait, SVO categorizes decision makers according to their predominant preferences regarding the distribution of (financial) resources between themselves and at least one other person (e.g., Balliet, Parks, & Joireman, 2009; Balliet & Van Lange, 2013). Questionnaire surveys of trait SVOs in a number of countries have found that approximately 57% of people are predominantly cooperative, motivated to maximize the joint or collective payoff of the player pair or group; 27% are individualistic, motivated to maximize their own individual payoffs; and 16% are competitive, motivated to maximize the difference between their own and their co-players' payoffs (Au & Kwong, 2004). The *prosocial* orientation is an umbrella term combining cooperative, altruistic (motivated to maximize the payoffs of their co-players), and equality-seeking (motivated to minimize the difference in payoffs between themselves and their co-players) motives. Alternatively, SVO can also be interpreted as a state variable, influenced by situational factors and therefore experimentally manipulable, and this was the form in which the concept was originally introduced (Messick & McClintock, 1968).

In two experiments using an eight-legged exponential Centipede game, Pulford, Krockow, Colman, and Lawrence (2016) used framing instructions designed to induce

different state SVOs in their players. They compared four different treatment conditions: cooperative, competitive, individualistic, and a neutral control condition, the manipulation consisting of small “reminders” inserted into the written instructions. In the cooperative condition, the reminder was, “Please remember: Your decisions and those of the other person will determine how many points you both earn;” in the competitive condition, it was, “Please remember: Your decisions and those of the other person will determine who wins”; in the individualistic condition, it was, “Please remember: Your decisions and those of the other participant will determine how much money you receive for yourself”; and in the neutral condition, no reminder was given. This manipulation yielded significant effects, with the individualistic condition producing higher levels of cooperation than the competitive condition. Players in the neutral condition, who were given no explicit motivational induction, exhibited largely competitive play. Trait SVO, measured with a standard questionnaire, affected cooperation differently depending on the state SVO that had been experimentally induced. In particular, players with individualistic or competitive trait SVO defected significantly more frequently than other players in most framings of the Centipede games.

Additional support for the importance of other-regarding motivations was provided by a qualitative study on decision making in Centipede games (Krockow, Pulford, & Colman, 2016). Verbal protocol analysis revealed that very few subjects used sophisticated recursive reasoning in the game. Interestingly, the few sophisticated reasoners were among the ones who cooperated most consistently. Additionally, a large number of motives for cooperation was found (32 motives); their importance changed with the stage of the game. Initial cooperation was largely associated with *activity bias*—a tendency of subjects in experiments to do prefer activity (in Centipede games cooperation, allowing the game to continue) to inactivity (defection, stopping the game)—whereas cooperation towards the end of the game

was more frequently linked to prosocial value orientations. These researchers also reported that subjects attached meaning to the response latencies of their co-players and interpreted delays as warning signs of likely defection on the next move.

Personality traits. Atiker's (2012) doctoral dissertation investigated the influence of personality traits on play in the Centipede game. Subjects completed a personality questionnaire (the International Personality Item Pool) and then engaged in 12 different Centipede games (drawn from a pool of 17 Centipede games with different payoff functions). A significant correlation was found between the personality variable "performance motivation" and the choice at Node 1, indicating that highly motivated individuals adhered to the game-theoretic solution more frequently than others. High self-esteem and intellectuality also yielded a more frequent use of BI reasoning and, thus, lower cooperation levels. Risk-takers and assertive personalities, on the other hand, were shown to cooperate longer than others.

Trust. Based on two studies on cultural differences between Japanese and UK subjects in Centipede-type decision making, Krockow, Takezawa, Pulford, Colman, and Kita (2016) and Krockow, Takezawa, Pulford, Colman, Smithers, Kita, and Nakawake. (2016) suggested that differences in trust may account for the significantly different cooperation levels observed. Both studies showed that Japanese subjects cooperated significantly more frequently in linearly increasing Centipede games than UK subjects. In fact, in one experiment almost 30% of all games completed by the Japanese subjects reached the natural end, whereas the percentage in the UK was zero. Furthermore, Japanese subjects were significantly more likely to purchase commitment-enhancing tools in order to increase security and stability in the game than were UK subjects. A number of individual difference variables were assessed for both studies, including SVO, risk-taking and general trust. Some evidence was found that prosociality and ethical risk-taking may be related to cooperation in

the Centipede game, but general trust did not differ between countries and was found to be unrelated to decision making.

The authors attributed the cross-cultural differences in decision making to different types of trust prevalent in the samples. Although the questionnaire measures suggested similar levels of *general trust* (applicable to one-shot situations of high social uncertainty), it is likely that the samples differed in their levels of *assurance-based trust* (applicable to committed, longer-term relationships characterized by repeated interactions with the same individual). Since the Centipede game could be classified as a decision context necessitating the second type of trust, it is possible that higher levels of assurance-based trust in the Japanese sample caused the exceptional cooperation levels. This explanation was further supported by the frequent Japanese choices of commitment-enhancing tools (where offered), showcasing their cultural preference for security and loyalty in relationships. It also links with previous findings indicating that the Japanese culture is traditionally characterized by high levels of assurance-based trust, whereas US culture shows higher levels of general trust (Kiyonari, Yamagishi, Cook, & Cheshire, 2006; Kuwabara et al., 2007; Yamagishi & Yamagishi, 1994; Yuki, Maddux, Brewer, & Takemura, 2005).

Summary of Individual Differences

Individual differences have received far too little attention from experimental researchers studying reciprocal cooperation in Centipede games. The few studies that have appeared suggest that individual differences may have important effects. Research on Centipede play by expert Chess and GO players has yielded strikingly inconsistent findings, but the apparently well controlled experiment reported by Levitt et al. (2011) suggests that even chess grandmasters, who have an ability to perform BI reasoning when analysing chess positions, and who used this ability in Race to 100 games, were either unable or unwilling to follow its dictates in the Centipede game. Gerber and Wichardt (2010) showed that many

ordinary subjects (not chess experts) have difficulty applying iterative reasoning and comprehending its logic in the context of the Centipede game, and this suggests that limited cognitive ability may account, at least in part, for recurrent deviations from the game-theoretical solution. But the possibility remains that expert chess players who deviate from BI do so not because they fail to understand its logic but because they believe that they can do better by cooperating.

The study of other-regarding preferences in general and trait SVO in particular has important implications for understanding individual differences in Centipede play. The experiments of Pulford, Krockow, Colman, and Lawrence (2016) show that state SVO, manipulated by framing the task in different ways, can have significant effects on levels of cooperation in Centipede games, and that neutral framing tends to elicit competitive rather than individualistic play. These findings suggest that the standard assumption in experimental games that players are individualistically motivated may be questionable, which in turn has important implications for experimental gaming research. Initial research on personality traits links performance motivation to equilibrium play but so far no published research has appeared on this topic. Finally, a culturally-specific type of trust, assurance-based trust of the type observed in committed, long-term relationships, may influence decision making in the game. In two studies by Krockow, Takezawa, Pulford, Colman, and Kita (2016) and Krockow Takezawa, Pulford, Colman, Smithers, Kita and Nakawake (2016) it was found that traditionally more committed and loyal Japanese subjects cooperated significantly more frequently in the Centipede game compared to a UK sample of comparable age and education.

Discussion and Conclusions

The research reviewed in this article shows that human decision makers do not follow the game-theoretic prescription of defecting at the earliest opportunity in the Centipede game.

They tend to do so only under extreme conditions—three or more players, very high stakes, very costly GO moves, high risk costs or payoff asymmetry, and time pressure, all or at least most of these factors operating together. Findings from the vast majority of experiments lacking these extreme conditions have reported rampant cooperation. Typical findings are that few players defect at the very first decision node; most make a few cooperative moves at least, so that the most popular exponential Centipede games typically end at a decision node between a quarter and two-thirds of the way to the last decision node (see Figure 4); and in most experiments, close to 10% of players cooperate altruistically even at the final decision node, or the penultimate decision node in games with zero payoffs in the final terminal node.

Among the various factors that have been found to increase or decrease levels of cooperation, the most well established include the following. Constant-sum and Take-it-or-leave-it payoff functions, both of which are intrinsically competitive, result in much earlier defection, whereas linear payoff functions generally encourage more cooperative moves and later defection. More generally, high risk cost—the proportion of payoff lost as a consequence of cooperating if the co-player defects immediately after—and high payoff asymmetry lead to earlier defection, and increasing the number of players may also lead to earlier defection, but this needs further investigation. Repeating the game many times tends to result in small learning effects in the direction of earlier defection, although these effects were found to depend on the particular game design employed, with high-stakes multi-player games generating steeper learning curves. Group decision makers tend to defect earlier than individuals. There is no unambiguous evidence that high cognitive ability leads to earlier defection, but social value orientations may have an effect, with prosocial players making more cooperative moves than others.

The most fundamental question is why anyone cooperates at all in Centipede games. Why do players not follow the rational prescription of game theory and defect at the earliest

opportunity? The backward induction (BI) argument is compelling: it appears to lead inexorably to the conclusion that any rational player will defect at the earliest opportunity, and hence that every Centipede game should stop at the first decision node, unless Player A is irrational. One possibility is that the BI argument may be less persuasive than it appears to be on account of an unnatural hidden assumption, namely that expectations about co-players' future actions are unaffected by observations of their past actions (Colman, Krockow, Frosch, & Pulford, 2016). According to the BI argument, a rational player will defect at any decision node because of certain knowledge that the assumedly rational co-player will respond to a cooperative move by defecting immediately after. But at the third decision node, for example, a player knows that the co-player has already cooperated once, violating BI rationality; therefore, it could be argued that there is no obvious reason to expect this same co-player to defect at the next decision node. The argument assumes that players retain their assumptions of their co-players' BI rationality even after observing evidence contradicting it, and many players may find this hard to swallow. This apparent weakness of the BI argument as applied to the Centipede game cannot explain why people cooperate, but it could explain why BI reasoning does not cause them to defect at the first opportunity.

A more popular explanation for why people do not typically follow BI (e.g., Gerber & Wichardt, 2010; Palacio-Huerta & Volij, 2009) is what we shall call the *cognitive burden* explanation. The basic idea is that BI is cognitively demanding and that most players lack the concentration, motivation, or strategic reasoning skills to understand it, and consequently they do not realize that it is in their own interests to defect as soon as possible. The fact that BI involves multiple iterative steps of argument, starting from the final decision node and working back to the first, is not necessarily problematic in itself. Extending an insightful observation made by Milgrom (1981), we offer the following *Gedankexperiment*. Suppose a teacher were to announce in a classroom full of 12-year-old children that “this lesson is

cancelled because there has been a power cut”. That information would immediately become common knowledge among the children, and we suggest that they would have no difficulty understanding that every child knows it, knows that every child knows it, and so on *ad infinitum*, without having to compute any separate steps of the argument in their heads.

The fact that the BI argument relies not only on iterated reasoning but also on *counterfactual conditionals*—for example, “My co-player would not choose GO; but hypothetically, what would I do if she did choose GO?”—adds an additional and possibly heavier layer of cognitive difficulty. But this may be beside the point, because there are reasons for believing that players’ failure to follow BI does not arise from their inability to understand it. If cognitive burden is indeed the true explanation, then surely games that are repeated over many rounds should show rapid convergence to the subgame-perfect equilibrium and defection at the first decision node, as players gradually come to understand the problem better; but typically only very modest increases in early defection (sometimes none at all) have been observed in conventional two-player sequential-choice Centipede games (e.g., Fey et al. 1996; McKelvey & Palfrey, 1992; Pulford, Colman, Lawrence, & Krockow, 2016).

A third, more subtle, explanation is that players deviate from BI because they do not expect their co-players to be fully rational. We call this the *common knowledge breakdown* explanation. For example, Aumann (1995) has argued that “CKR [common knowledge of rationality] is an ideal condition that is rarely met in practice; when it is not met, the inductive choice may be not only unreasonable and unwise, but quite simply irrational” (p.18). Heifetz and Pauzner (2005) proved that if perfectly rational players ascribe some small probability to their co-players deviating from BI, then strong deviations from BI can occur. Note that this explanation retains the standard assumption that the players are rational; it relaxes only the assumption that this is common knowledge. The common knowledge breakdown explanation

is reminiscent of a comment by Binmore (1987) that “good poker players do not play maximin [game-theoretically rational] strategies against those they have a good reason to suppose to be poor players. They deviate from the maximin strategy in the hope of exploiting the expected bad play of their opponents” (p. 196).

The common knowledge breakdown explanation can be traced back to an analysis by Kreps, Milgrom, Roberts, and Wilson (1982) of the finitely repeated Prisoner’s Dilemma game, in which a similar BI argument applies. The “Gang of Four” (as they are known in game theory circles) proved that two players who are themselves perfectly rational, but who each believe that there is a small probability that the other player is irrational, will deviate from equilibrium play to cultivate reputations for cooperativeness and elicit cooperation from their co-players. Indeed, a qualitative study reported by Krockow, Pulford, and Colman (2016) suggests that the most common motives for initial cooperation in the Centipede game include curiosity and probing (the wish to test the co-players’ strategies in the game).

If both players know that they are rational, and both know that they know it, but do not know it to infinite recursive layers, then it is called mutual knowledge, rather than common knowledge, of rationality. Aumann (1992) has shown that “one can carry mutual knowledge of rationality to any finite level short of common knowledge, and still get the same effect: the players will be motivated to play mutually beneficial but seemingly irrational strategies” (p. 226). It is only with full common knowledge that BI becomes irresistible. This common knowledge breakdown explanation, in its various forms, has some appeal, but experiments designed specifically to test it in the finitely iterated Prisoner’s Dilemma game (Andreoni & Miller, 1993; Cooper, DeJong, & Forsythe, 1996) and the Centipede game (McKelvey & Palfrey, 1992) have shown that it cannot explain all violations of backward induction. Experimental results stubbornly suggest that some players behave cooperatively or

altruistically irrespective of any knowledge or beliefs that they may hold about the rationality of their co-players.

This suggests that there may be a more fundamental explanation for cooperative play in Centipede games. The need for a different explanation is also evident in the powerful intuition that it is rational to cooperate in this game. To many people, it seems natural to defect at the end but pathologically pessimistic to defect at the beginning (Aumann, 1992); to others, it seems natural to cooperate even at the end, especially as, by then, the co-player has also shown a willingness to cooperate, and one good turn deserves another. Even people who understand the logic of BI perfectly and expect their co-players to act rationally appear to be inclined to reject it as the basis for playing the game. A prime example is the mathematician, game theorist, and Nobel laureate Reinhard Selten, who revealed that he would not follow BI in a game closely related to the Centipede game. He added: “My experience suggests that mathematically trained persons recognize the logical validity of the induction argument, but they refuse to accept it as a guide to practical behavior” (Selten, 1978, pp. 132–133).

Another related reason why it is difficult to accept the BI solution is that it seems illogical to define rationality in terms of payoff maximization when irrational players earn higher payoffs than rational players. Perfectly rational players can only ever earn the payoffs available at the game’s first terminal node, whereas ordinary experimental subjects almost invariably earn much more. Exactly the same contradiction applies in the repeated Prisoner’s Dilemma game, but the paradox seems sharper and more difficult to live with in the Centipede game. These intuitions cast doubt on the explanations based on cognitive burden and common knowledge breakdown, and they need to be factored in to any explanation of cooperation in Centipede games.

We seem driven to an explanation in terms of irrationality—at least, the narrow conception of irrationality in behavioural game theory, where payoffs are taken as given. If

we assume that players are not motivated solely to maximize their own payoffs but are driven by other-regarding preferences, and that they expect their co-players to be similarly motivated, then we can understand not only the empirical evidence of cooperative play but also the almost irresistible intuition that it makes sense to cooperate in a Centipede game. Almost a century and a half ago, Edgeworth (1881, pp. 102–104) introduced the idea of other-regarding payoff transformations. If the objective payoffs (monetary values, for example, or payoffs as displayed in an experimental game) to Player 1 and Player 2 in any particular outcome are v_1 and v_2 respectively, and if u_1 and u_2 are the players' actual utilities, representing their true preferences, then a simple mathematical model of Player 1's other-regarding utility is the linear equation $u_1 = \alpha v_1 + (1 - \alpha)v_2$, and Player 2's is $u_2 = \beta v_1 + (1 - \beta)v_2$. Here, α and β are parameters determined by the nature of the players' other-regarding preferences. In the simplest possible case, if a player has a utility function that weights both objective payoffs equally—the player cares equally about both players' objective payoffs, and nothing else matters—then the parameters are equal to $1/2$ and we have the cooperative SVO of interdependence theory (Rusbult & Van Lange, 2003). As an example, let us take the first terminal node in the game depicted in Figure 1. Let us call Player A “Player 1” and Player B “Player 2”, to match the notation we are using. The objective payoffs are 2 to Player 1 and 1 to Player 2, and under the cooperative SVO, Player 1's utility for that outcome is $u_1 = 2/2 + 1/2 = 1.5$. Player 1's utility for the second terminal node in the same game is $u_1 = 1/2 + 6/2 = 3.5$, and so on. In any linear or exponential Centipede game with social gains—that is, one in which the joint payoff or pot increases from one terminal node to the next—if both or all players have cooperative utility functions, then it is rational for them to cooperate at every decision node, because cooperation can only yield a higher utility than defecting, each successive terminal node being preferred to its predecessor, and the BI argument is simply irrelevant. The interpretation is that we are dealing with collectively rational players who care

about the joint payoff of the players or social gains rather than just their own personal payoffs, and it is rational for them to cooperate at every decision node. A cooperative move provides a benefit b at some cost c to the player pair, and this is always nonnegative, because $c \leq b$. If players are to some degree motivated in this way, then that would explain the evidence that we have reviewed for cooperative moves in linear and exponential Centipede games, and it would also explain why far fewer cooperative moves and much earlier defections are observed in constant-sum Centipede games, because players with a cooperative utility function prefer every terminal node in a constant-sum of game equally.

We are not suggesting that human decision makers necessarily have such simple other-regarding preferences as the cooperative SVO. In reality, other-regarding preferences seem likely to weight a player's own payoff more than the co-player's, and there are other considerations, such as inequality aversion and altruism that are frequently associated with cooperativeness, leading to the identification of the hybrid prosocial SVO (Van Lange, 1999). Nonetheless, there is a substantial body of evidence suggesting that the cooperative SVO is predominant in about 57% of people (Au & Kwong, 2004; Murphy, Ackermann, & Handgraaf, 2011). In the light of such findings, it seems naive to assume that all experimental subjects are predominantly individualistic, and hence that the objective payoffs as presented to them in experimental games necessarily reflect their actual utilities. Further research is needed to clarify the motivations at work in Centipede games and to analyse the implications for styles of play, but it seems likely that other-regarding preferences provide at least part of the explanation for cooperation in Centipede games and also for the intuitive appeal of cooperative moves.

In conclusion, the Centipede game is regarded by many decision and game theorists as a prize exhibit in the museum of human irrationality, exceeding even the Prisoner's Dilemma game in its propensity to elicit foolish behaviour. Our systematic review of research

into Centipede-type interactions suggests that this view overlooks the subtleties of reciprocal cooperation and underestimates the astuteness of experimental subjects. Experimental findings suggest that the game-theoretic solution is largely irrelevant, even among players who are fully capable of backward induction reasoning. Most people have a strong impulse to cooperate, and this impulse is not necessarily irrational, because it seems to arise from prosocial, other-regarding preferences that take account not only of their own payoffs but also those of their co-players. In situations with the strategic structure of Centipede games, people frequently display a form of collective rationality that rewards them with better payoffs in the long run although it falls outside the comprehension of orthodox game theory.

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Footnote

¹ Inclusion criteria for Figures 3 and 4: (a) Published in peer-reviewed journal or book; (b) experiment conducted using the direct response method (as opposed to strategy method) for response elicitation; and (c) all quantitative measures displayed in figures were available to the authors.

Appendix

Synopsis of Experiments Included in the Review

Game tree	Payoff function	Rounds	Treatment conditions	Elicitation method	% stopping at SPE ¹	% reaching last exit node	Mean exit node ²
Atiker (2012), unpublished manuscript retrieved online							
Example game: <p> 40 25 </p>	Mixed	12	N/A	Strategy method	See results reported by Atiker et al. (2012)	See results reported by Atiker et al. (2012)	See results reported by Atiker et al. (2012)
This experiment investigated the influence of personality traits on play in the Centipede game. Subjects completed a personality questionnaire (the International Personality Item Pool) and then engaged in 12 different Centipede games (drawn from of a pool of 17 Centipede games with different payoff functions), using the strategy method. The Centipede data reported in this study are identical to those presented by Atiker, Neilson, and Price (2011), (see below). However, instead of focusing on differences between the 17 different Centipede games used, this manuscript examined the relationships between personality and game play. A significant correlation was found between the personality variable “performance motivation” and the choice at Node 1, indicating that highly motivated individuals adhered to the game-theoretic solution more frequently than others. High self-esteem and intellectuality also yielded a more frequent use of BI reasoning and, thus, lower cooperation levels. Risk-takers and assertive personalities, on the other hand, were shown to cooperate longer than others.							
Atiker, Neilson, and Price (2011), unpublished manuscript retrieved online
<p> 40 25 </p>	Increasing sum (linear)	12	C1: Standard Centipede game	Strategy method	4.0	7.9	6.15/0.51

¹ SPE is the abbreviation of “subgame perfect equilibrium”.

² The first figure displays the mean exit node for the respective game. The second figure displays the standardized mean exit point of the game tree where the games ended. It provides a standardized measure of the exit node to increase comparability across studies. The standardized figure was obtained by dividing the mean exit node by the game length (i.e., the number of terminal nodes).

	44 0	Constant-sum	<div></div>	C2: Constant-sum Centipede game	16.8	0	6.06/ 0.50
	36 23	Increasing sum (linear)		C3: Early moves games (7 variations)	0	5.9	6.06/ 0.51
	40 25	Increasing sum (linear)		C4: Activity bias game (2 variations)	24.8	0.2	5.83/ 0.49
	36 23	Increasing sum (linear)		C5: “Beliefs about co-player’s rationality” games (4 variations)	13.7	0	4.06/ 0.34
	36 23	Increasing sum (linear)		C6: Focal point games (2 variations)	34.7	0.8	1.94/ 0.16
<p>This study aimed to test a number of possible reasons that could explain the recurrent deviations from the Centipede’s sub-game perfect Nash equilibrium. These reasons included (1) joint payoff maximization, (2) lack of common knowledge of rationality, (3) activity bias, and (4) lack of focal points in the standard game. Using a within-subjects design, all participants played 12 Centipede games (drawn from a pool of 17) with slightly different, carefully manipulated payoff functions designed to isolate and measure the influence of the four possible reasons that could explain deviations from the equilibrium. Due to limited space, only six example treatment conditions (out of 17) are displayed in this summary. Participants were randomly re-matched after each of the 12 game rounds and game order varied across testing sessions. The strategy method was used to yield a richer data set. The Centipede data reported in this study are identical to those presented by Atiker (2012). However, instead of focusing on personality traits, this manuscript examined the differences between the 17 variations of Centipede. The results suggested that activity bias (i.e. the wish for</p>							

the co-player to also have an influence on the payoffs) had an impact on decision making. The most important factor, however, was found to be the existence of focal points: Terminal nodes with payoffs breaking the game's regular payoff pattern were found to elicit disproportionately high numbers of exit moves.

Baghestanian and Frey (2014)

Smaller choice	Possible higher choices of opponents	Payoff of A	Payoff of B	Sum		Increasing sum (exponential)	1	C1: Centipede game	Strategy method (game presented in normal form)	0	32.6	10.49 0.75
1	{2, 4, 6, 8, 10, 12, 14}	40	10	50								
2	{3, 5, 7, 9, 11, 13}	20	50	70								
3	{4, 6, 8, 10, 12, 14}	80	20	100								
4	{5, 7, 9, 11, 13}	30	110	140				C2: Traveler's dilemma		N/A	N/A	N/A
5	{6, 8, 10, 12, 14}	160	40	200								
6	{7, 9, 11, 13}	60	220	280								
7	{8, 10, 12, 14}	320	80	400				C3: Kreps game		N/A	N/A	N/A
8	{9, 11, 13}	110	450	560								
9	{10, 12, 14}	640	160	800								
10	{11, 13}	220	900	1120								
11	{12, 14}	1280	320	1600				C4: Matching Pennies game		N/A	N/A	N/A
12	{13}	440	1800	2240								
13	{14}	2560	640	3200								

Using a sample of professional Go players, the authors compared decision making across four games – a normal form Centipede game, a Traveler's dilemma, a Kreps game and a Matching Pennies game, the former two of which are characterized by inefficient equilibrium solutions. They further measured strategic reasoning skills by assessing the subjects' Go Elo scores and analytic reasoning skills with the help of the Frederick cognitive reflection test. Subjects were found to deviate from the Nash equilibria in Centipede games and Traveler's dilemmas but not in the other two, suggesting that those deviations were less likely caused by a lack of cognitive ability. However, decision making in those two games correlated with the two different reasoning measures, with higher Elo scores related to lower cooperation levels and higher CRT scores related to higher cooperation levels. These findings suggest that different types of reasoning may affect decision making in the Centipede game.

Basu, Mitra, and Gupti (2013)

[illegible]

Cox and James (2012)										“Take-it-or-leave-it”	3 rounds of 10 games from different conditions	C1: Tree format with sequential moves	Direct response method Direct response method	55.7	0	1.79/ 0.16																												
												C2: Clock format with sequential moves		86.2	0	1.15/ 0.10																												
<table><tr><th>Player \ Clock reading</th><th>1</th><th>2</th><th>3</th><th>...</th><th>7</th><th>8</th><th>9</th><th>10</th></tr><tr><th>P1</th><td>a+2</td><td>0</td><td>a+4</td><td>...</td><td>0</td><td>a+10</td><td>0</td><td>a+12</td></tr><tr><th>P2</th><td>0</td><td>b+2</td><td>0</td><td>...</td><td>b+8</td><td>0</td><td>b+10</td><td>0</td></tr></table>												Player \ Clock reading		1	2	3	...	7	8	9	10	P1	a+2	0	a+4	...	0	a+10	0	a+12	P2	0	b+2	0	...	b+8	0	b+10	0	C3: Tree format with simultaneous moves	Direct response method (with simultaneous moves at each node)	72.6	0	1.45/ 0.13
Player \ Clock reading	1	2	3	...	7	8	9	10																																				
P1	a+2	0	a+4	...	0	a+10	0	a+12																																				
P2	0	b+2	0	...	b+8	0	b+10	0																																				
<table><tr><th>Player \ Clock reading</th><th>1</th><th>2</th><th>3</th><th>...</th><th>7</th><th>8</th><th>9</th><th>10</th></tr><tr><th>If P1 decides to STOP first</th><td>a+2 0</td><td>a+3 0</td><td>a+4 0</td><td>...</td><td>a+9 0</td><td>a+10 0</td><td>a+11 0</td><td>a+12 0</td></tr><tr><th>If P2 decides to STOP first</th><td>0 b+1</td><td>0 b+2</td><td>0 b+3</td><td>...</td><td>0 b+8</td><td>0 b+9</td><td>0 b+10</td><td>0 b+11</td></tr></table>										Player \ Clock reading	1	2	3	...	7	8	9	10	If P1 decides to STOP first	a+2 0	a+3 0	a+4 0	...	a+9 0	a+10 0	a+11 0	a+12 0	If P2 decides to STOP first	0 b+1	0 b+2	0 b+3	...	0 b+8	0 b+9	0 b+10	0 b+11	C4: Clock format with simultaneous moves	96.4	0	1.06/ 0.10				
Player \ Clock reading	1	2	3	...	7	8	9	10																																				
If P1 decides to STOP first	a+2 0	a+3 0	a+4 0	...	a+9 0	a+10 0	a+11 0	a+12 0																																				
If P2 decides to STOP first	0 b+1	0 b+2	0 b+3	...	0 b+8	0 b+9	0 b+10	0 b+11																																				
<p>This study merged aspects of the Centipede game with those of Dutch auctions. The authors used a 2x2x2 design and manipulated the game type (Centipede game/Dutch auction), the institutional format it was presented in (clock/tree) and the move order (sequential/simultaneous moves). For the purpose of this review, the conditions using Dutch auctions have been omitted. The study found that presenting the Centipede games in clock format produced significantly different results from presenting it in the</p>																																												

standard tree format; subjects made decisions closer to the game theoretical solution. The earliest STOP moves were reported for the condition which combined clock format with simultaneous move structure.																										
Cox and James (2015)																										
<div><div><div>1</div><div>2</div><div>3</div><div>4</div></div><div><div>12.80</div><div>3.20</div></div><div><div>0.80</div><div>0.40</div><div>3.20</div><div>1.60</div></div><div><div>0.20</div><div>1.60</div><div>0.80</div><div>6.40</div></div></div>				Increasing sum (exponential)	10	C1: Replication of McKelvey and Palfrey's (1992) low-stake 4-node game, adjusted for inflation	Direct response method	21.0	0	2.19/ 0.44																
<div><div><div>1</div><div>2</div><div>3</div><div>4</div></div><div><div>6.40</div><div>1.60</div></div><div><div>0.40</div><div>0.20</div><div>1.60</div><div>0.80</div></div><div><div>0.10</div><div>0.80</div><div>0.40</div><div>3.20</div></div></div>				Increasing sum (exponential)	3x10 rounds of different Centipede games	C2: Replication of McKelvey and Palfrey's (1992) low-stake 4-node game		24.3	6.0	2.62/ 0.52																
<div><div><div>1</div><div>2</div><div>3</div><div>4</div></div><div><div>6.40</div><div>0</div></div><div><div>0.40</div><div>0</div><div>1.60</div><div>0</div></div><div><div>0</div><div>0.80</div><div>0</div><div>3.20</div></div></div>				"Take-it-or-leave-it"		C3: Take it or leave it payoff function		54.3	0.7	2.13/ 0.43																
<div><div><div>1</div><div>2</div><div>3</div><div>4</div></div><div><div>6.40</div><div>0</div></div><div><div>0.40</div><div>0</div><div>1.60</div><div>0</div></div><div><div>0</div><div>0.80</div><div>0</div><div>3.20</div></div></div>				"Take-it-or-leave-it"		C4: Take-it-or-leave-it payoff function with 10 second time frame for making a move		58.7	0.7	1.98/ 0.40																
<table><tr><td>Clock reading</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr><tr><td>P1</td><td>0.40</td><td>0</td><td>1.60</td><td>0</td><td>6.40</td></tr><tr><td>P2</td><td>0</td><td>0.80</td><td>0</td><td>3.20</td><td>0</td></tr></table>				Clock reading		1		2	3	4	5	P1	0.40	0	1.60	0	6.40	P2	0	0.80	0	3.20	0	"Take-it-or-leave-it"	C5: Take-it-or-leave-it payoff function with 10 second time	50.0
Clock reading	1	2	3	4	5																					
P1	0.40	0	1.60	0	6.40																					
P2	0	0.80	0	3.20	0																					

			frame for making a move; game presented in clock format				
<p>This experiment included a replication of one of McKelvey and Palfrey's (1992) original Centipede games as well as four other game conditions that differed in stake size, payoffs to non-Takers ("Take-it-or-leave-it" game versus standard Centipede game), time pressure and the format presented in (clock versus tree format). The authors found that both higher stakes and the introduction of zero payoffs to non-takers (i.e., adhering to a "Take-it-or-leave-it" payoff function) led to earlier unravelling and lower overall cooperation compared to the standard Centipede game used. Interestingly, the conditions introducing time pressure and clock format did not yield lower cooperation levels compared to the "Take-it-or-leave-it" game without these additional design features, which is in contrast with the findings by Cox and James (2012), (see above).</p>							
El-Gamal, McKelvey and Palfrey (1993)							
<p>Centipede game tree for El-Gamal et al. (1993). Player 1 moves first, choosing between 4 and 1. If Player 1 chooses 4, Player 2 moves, choosing between 2 and 8. If Player 2 chooses 2, Player 3 moves, choosing between 16 and 4. If Player 2 chooses 8, Player 3 chooses between 16 and 4. The terminal payoffs are (4, 2, 16) and (4, 8, 4).</p>	Increasing sum (exponential)	2	N/A	Direct response method	31.6	14.5	2.24/0.56
<p>This study investigated learning in a three-move Centipede game. The researchers applied two different models to the data to test whether reputation building (non-sequential model) or population learning (sequential model) could account for the findings. The authors found support for the second model, indicating that individuals learned about the population of players during each game they played and updated their strategies in response to previous experiences.</p>							
Farina and Sbriglia (2008a)							
<p>Centipede game tree for Farina and Sbriglia (2008a) with two sets of payoffs. The top set has payoffs (40, 30, 80, 70, 120, 110) and (10, 60, 50, 100, 90, 140). The bottom set has payoffs (140, 110, 180, 150, 220, 190) and (90, 160, 130, 200, 170, 240).</p>	Increasing sum (linear)	2	C1: Low-stake, homogeneous pairing	Direct response method	10.0	6.0	4.22/0.60
			C2: Low-stake, heterogeneous pairing		5.0	10.1	4.88/0.70
			C3: High-stake, homogeneous pairing		28.0	0	3.19/0.46
			C4: High-stake, heterogeneous pairing		10.0	2.0	3.76/0.54

			heterogeneous pairing				
<p>This experiment (which was also discussed in a chapter by Farina & Sbriglia, 2008b) examined the effects of stake size and knowledge of the co-players strategic profile in a trust game on decision making in the Centipede game. Subjects completed a two-stage trust game using the strategy method and then played two Centipede games with low and high stake sizes. Before engaging in the Centipede game, the players were informed about their co-players' choices in the trust game, identifying them as selfish, altruistic or reciprocating individuals. The results indicate that higher stake sizes significantly reduced cooperation levels. Overall, information about choices in the trust game decreased cooperation in the Centipede game, which was largely due to the very early game exits by homogenous pairings of selfish individuals.</p>							
Fey, McKelvey, and Palfrey (1996)							
<div> </div>	Constant-sum	10	C1: Game length: 6 nodes	Direct response method	59.1	0	1.50/0.21
<div> </div>							45.1
<p>The authors reported findings from two constant-sum Centipede games with varying lengths. Subjects recurrently deviated from the unique Nash equilibrium but STOP probabilities tended to increase with every node passed. Furthermore, with increasing experience in the game, STOP moves were chosen earlier. The authors proposed the Quantal Response Equilibrium model, accounting for reasoning mistakes and learning, as the best match of their findings.</p>							
Gamba and Regner (2015), unpublished manuscript retrieved online							
<div> </div>	Increasing sum (linear)	40	C1: Personal-direct information	Direct response method	0.6	5.0	4.51/0.64
C2: Public-direct information			0.2		29.1	5.84/0.83	
C3: Personal-strategy information			Strategy method (variation)	0.7	7.0	4.51/0.64	
C4: Public-strategy information				0.2	22.8	5.59/0.80	

This experiment manipulated the type of information about the co-player's behaviour (personal information about own game outcome only vs. public information about all game outcomes from previous round) and the elicitation method in the games (direct response method vs. strategy method). Additionally, SVO was measured using a combination of questionnaire data from an SVO scale and behavioral data from a simple trust game; subjects were subsequently categorized as either pro-selfs or pro-socials. Finally, the authors assessed beliefs about the co-players' likely choices at different stages in the experiment. The results suggested that differences in the beliefs about the co-players and in consequent decision making are based on individual differences in prosocial preferences with pro-socials displaying higher initial cooperation rates than pro-selfs. The authors further reported that pro-selfs cooperated more frequently in games with public information (particularly when combined with the strategy method) compared to games with personal information only. This was explained by the fact that the additional information about choices of all players of opposite participant role (rather than just of the own co-player) led them to adapt their initially non-cooperative strategies in order to increase payoffs.

Gerber and Wichardt (2010)

	Increasing sum (linear)	10	C1: Standard Centipede (control)	Direct response method	0	12.0	6.73/ 0.75
<p>Payoffs for the case where Player B has chosen the insurance option.</p>			C2: Option to choose insurance tool: $\epsilon=0.5$; $c=2.5$		1.5	11.5	6.84/ 0.76
<p>Payoffs for the case where Player A has chosen the bonus option.</p>			C3: Option to choose bonus tool: $b=2.5$		0	56.0	8.07/ 0.90

The authors compared two treatment conditions where subjects could choose to purchase one of two tools to improve their payoff certainty in a linearly increasing Centipede game. The insurance tool at cost c offered a higher personal payoff in case the other person chose to STOP. The bonus tool involved offering the co-player an incentive of b for not ending the game. Even though both instruments should have been equally effective, only the bonus tool was frequently used by the subjects, leading to a significant delay in game termination. The authors explained this with a lower level of iterated reasoning ability required to understand the benefits of the bonus option. The findings demonstrated the challenges imposed by iterated reasoning processes and indicated that insufficient cognitive abilities could be a reason for deviation from Nash equilibrium in the Centipede game.

Horng and Chou (2012)								
Example game:		Increasing sum (exponential)	51	Medium risk-cost payoff function	Direct response method	No information	No information	No information
This study investigated the effects of risk cost, payoff symmetry and stake size on decision making in the Centipede game. The authors manipulated the risk associated with each GO move (personal payoff decreased by 90%, 50% or 20%) and found that high-risk games were stopped significantly earlier than low-risk games but only when combined with big stakes sizes. The study further examined the effects of the inherently unequal player roles and of games with either symmetrically or asymmetrically increasing payoffs to the two players. The disadvantaged players stopped significantly earlier than the advantaged players, indicating inequality aversion and a concern with fairness in the subjects.								
Huck and Jehiel (2004), unpublished manuscript retrieved online								
		"Take-it-or-leave-it"	50	C1: Information about other player's pass rates aggregated over all nodes from all rounds C2: Information about other player's pass rates at specific nodes; information was aggregated over all nodes from all rounds	Direct response method	No information	No information	No information
						No information	No information	No information

			C3: Information about other player's pass rates aggregated over all nodes from past five rounds		No information	No information	No information
			C4: Information about other player's pass rates at specific nodes; information was aggregated over all nodes from the past five rounds		No information	No information	No information
			C5: No informationrmation about other player's previous play		No information	No information	No information

This article reported findings on decision making in a competitive Take-it-or-leave it version of the Centipede game. The authors manipulated the amount of public information available about the co-player. Subjects were found to use both personal experience as well as public information (when available) for decision making. However, when stakes were very high, coarse public information was no longer taken into account. Finally, the provision of precise information on players' pass rates at specific nodes during the most recent trials (Condition 4) led to an increase of subjects using private and public information for their decision making. Learning rates were accordingly high in this condition, and the authors reported continuous unravelling up until the end of the experiment.

Kawagoe and Takizawa (2012)									
<div><div><div>1</div><div>2</div><div>3</div><div>4</div><div>5</div><div>6</div></div><div><div>0.40</div><div>0.20</div><div>1.60</div><div>0.80</div><div>6.40</div><div>3.20</div></div><div><div>0.10</div><div>0.80</div><div>0.40</div><div>3.20</div><div>1.60</div><div>12.80</div></div></div> <div>25.60 6.40</div>	Increasing sum (exponential)	1	C1: Payoff function: exponential	Direct response method	2.3	6.8	5.09/ 0.73		
<div><div><div>1</div><div>2</div><div>3</div><div>4</div><div>5</div><div>6</div></div><div><div>1.60</div><div>1.20</div><div>2.30</div><div>0.68</div><div>2.69</div><div>0.38</div></div><div><div>1.60</div><div>2.00</div><div>0.90</div><div>2.52</div><div>0.51</div><div>2.82</div></div></div> <div>2.92 0.28</div>	Constant-sum		C2: Payoff function: Constant-sum		34.1	0	1.95/ 0.28		
The authors studied decision making in exponentially increasing and constant-sum Centipede games, merging their data with results from McKelvey and Palfrey (1992), Palacios-Huerta and Volij (2009) and Levitt et al. (2011), who all used games with the same payoff function. A level-k model, assuming that that all players are selfishly motivated but differ in their levels of reasoning abilities, provided the best match of findings in the exponential Centipede game.									
Krockow, Pulford and Colman (2015)									
<div><div><div>1</div><div>2</div><div>3</div><div>4</div><div>5</div><div>6</div><div>7</div><div>8</div></div><div><div>0.40</div><div>0.20</div><div>1.60</div><div>0.80</div><div>6.40</div><div>3.20</div><div>25.60</div><div>12.80</div></div><div><div>0.10</div><div>0.80</div><div>0.40</div><div>3.20</div><div>1.60</div><div>12.80</div><div>6.40</div><div>51.20</div></div></div> <div>102.40 25.60</div>	Increasing sum (exponential)	20	C1: Standard exponential Centipede game	Direct response method	0.6	6.4	6.13/ 0.68		
<div><div><div>1</div><div>2</div><div>3</div><div>4</div><div>5</div><div>6</div><div>7</div><div>8</div></div><div><div>0.40</div><div>0.20</div><div>1.60</div><div>0.80</div><div>6.40</div><div>3.20</div><div>25.60</div><div>12.80</div></div><div><div>0.10</div><div>0.80</div><div>0.40</div><div>3.20</div><div>1.60</div><div>12.80</div><div>6.40</div><div>51.20</div></div></div> <div>0 0</div>	Increasing sum (exponential), zero-end		C2: Exponential Centipede game with zero-end		5.0	0	4.29/ 0.48		

	Take-it-or-leave-it		C3: Take-it-or-leave-it Centipede game		2.3	3.2	5.74/0.64
	Take-it-or-leave-it, zero-end		C4: Take-it-or-leave-it Centipede game with zero-end		0.1	1.0	5.12/0.57
<p>This study investigated cooperation in four Centipede games differing in their payoffs at the games' ends (positive versus zero) and payoff differences between players (moderate versus high difference). All four games were characterized by identical subgame perfect Nash equilibria and, thus, should have resulted in similar decision making across all treatment conditions. However, both zero-end payoffs and high payoff inequality led to significantly lower cooperation levels. Interestingly, combining these two competitive game aspects in a single game resulted in a weakening of their independent deterrent effects. These findings demonstrated the large influence that relatively small payoff changes can have on decision making. They further showed that the effects do not combine synergistically.</p>							
Krockow, Pulford and Colman (2016)							
	Increasing sum (exponential)	10	N/A	Direct response method	1.7	30	5.12/0.73
<p>This study used a qualitative approach to investigate decision making in the Centipede game. Verbal protocol analysis revealed that only few subjects employed sophisticated recursive reasoning in the game. Interestingly, however, the few sophisticated reasoners were the ones who cooperated most consistently. Additionally, a large number of motives for cooperation was found (32 motives); their respective importance changed with the stage of (or position) in the Centipede game. Initial cooperation in the game was largely associated with activity bias whereas cooperation towards the end of the game was more frequently linked to prosocial value orientations. The authors also reported that subjects attached meaning to the response latencies of their co-players and interpreted delays as indicators of likely defection on the next move.</p>							
Krockow, Takezawa, Pulford, Colman, & Kita (2016), unpublished manuscript retrieved from authors							
	Increasing sum (linear)	20	C1: Standard Centipede (control);	Direct response method	1.5	7.0	5.78/0.64

[illegible]

significantly more frequently than the British. The amount of payoff information also affected decision making. In Japan, both treatment conditions with incomplete information yielded significantly higher cooperation levels compared to the control. In the UK, only the condition with absolute payoff information produced significantly higher cooperativeness. Overall, the findings suggested that the Japanese players cooperated more frequently than the British players in stable, Centipede-type partnerships. This might be due to the assurance-based trust elicited by reciprocal interactions, a typical feature of Japanese culture. In situations with incomplete information, expectations about the stake size might have guided decision making, with lower expectations resulting in higher cooperation levels.

Krockow, Takezawa, Pulford, Colman, Smithers, Kita, & Nakawake (2016), unpublished manuscript retrieved from authors

<div><div><div><div><div>1</div><div>11</div><div>3</div></div><div><div>2</div><div>6</div><div>14</div></div><div><div>3</div><div>17</div><div>9</div></div><div><div>4</div><div>12</div><div>20</div></div><div><div>5</div><div>23</div><div>15</div></div><div><div>6</div><div>18</div><div>26</div></div><div><div>7</div><div>29</div><div>21</div></div><div><div>8</div><div>24</div><div>32</div></div></div><div>20</div><div>27</div></div></div>	Increasing sum (linear)	20	C1: Standard Centipede (control); Japanese sample	Direct response method	0	29.3	7.23/ 0.80
C2: Standard Centipede (control); European sample			11.7		0	3.76/ 0.42	
C3: Option to choose insurance tool: $\varepsilon=7$; $c=7$; Japanese sample			2.3		3.5	5.92/ 0.66	
C4: Option to choose insurance tool: $\varepsilon=7$; $c=7$; European sample			6.1		1.7	5.12/ 0.57	
C5: Option to choose bonus tool: $b=7$; Japanese sample			2.5		62.5	7.27/ 0.81	
C6: Option to choose bonus tool: $b=7$; European sample			5.6		12.2	5.18/ 0.58	
<div><div><div><div><div>1</div><div>11</div><div>3+ε-c</div></div><div><div>2</div><div>6</div><div>14-c</div></div><div><div>3</div><div>17</div><div>9+ε-c</div></div><div><div>4</div><div>12</div><div>20-c</div></div><div><div>5</div><div>23</div><div>15+ε-c</div></div><div><div>6</div><div>18</div><div>26-c</div></div><div><div>7</div><div>29</div><div>21+ε-c</div></div><div><div>8</div><div>24</div><div>32-c</div></div></div><div>35</div><div>27-c</div></div></div>							
<div><div><div><div><div>1</div><div>11-b</div><div>3+b</div></div><div><div>2</div><div>6</div><div>14</div></div><div><div>3</div><div>17-b</div><div>9+b</div></div><div><div>4</div><div>12</div><div>20</div></div><div><div>5</div><div>23-b</div><div>15+b</div></div><div><div>6</div><div>18</div><div>26</div></div><div><div>7</div><div>29-b</div><div>21+b</div></div><div><div>8</div><div>24</div><div>32</div></div></div><div>20</div><div>27</div></div></div>							

This study investigated European-Japanese differences in trust and cooperation in a linear version of the Centipede game with two treatment conditions offering similar insurance and bonus tools as Gerber and Wichardt (2011). Overall, Japanese subjects made significantly more cooperative choices in the standard Centipede game than Europeans. The authors explained these cultural differences with higher levels of assurance-based trust (as needed in committed, reciprocal relationships) in Japan. The Japanese also purchased significantly more tools than the Europeans, indicating their stronger preference for security and commitment in social interactions. The purchase of bonus and insurance tools significantly improved cooperativeness in both groups. However, the Japanese differed from the European participants as they interpreted refusal to purchase available tools as a signal of non-cooperative intent, causing a decrease in assurance-based trust and consequently also of cooperativeness.

Le Coq, Tremewan, and Wager (2015)

	Increasing sum (exponential)	1	C1: Subjects playing against ingroup member	Strategy method	4.2	22.9	5.29/ 0.66
			C2: Subjects playing against outgroup member		4.2	41.7	5.83/ 0.73

The study investigated whether group membership affected play in the Centipede game. After manipulating group identity, subjects either played against an ingroup member or an outgroup member. The subjects were further asked to indicate their beliefs about the other player's stop probabilities at different nodes. No significant differences were found between the conditions. In fact, the outgroup condition even produced higher cooperation levels. A possible explanation by the authors was that members of the same social group perceived each other as more similar and therefore predicted likely exit nodes with greater certainty. These beliefs, in turn, could have led to lower (albeit not significantly lower) levels of cooperation.

Levitt, List, and Sadoff (2011)

	Increasing sum (exponential)	1	C1: Type of Game: Centipede	Direct response method	3.9	6.9	4.23/ 0.60
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			C2: Type of Game: Race to 100		N/A	N/A	N/A
<p>The experiment compared decision making of expert chess players in the Centipede game and the “Race to 100” game. The latter was used to measure pure BI reasoning skill since its constant-sum winner-takes-it-all structure eliminates any social preferences. The chess players adhered to the game theoretical solution in only 3.9 percent of all games (compared to 69% reported in a similar study by Palacios-Huerta & Volij, 2009). Furthermore, not a single chess player with perfect performance in the Race to 100 game stopped the Centipede game at the first decision node. These findings indicated that cooperation in the Centipede game cannot fully be accounted for by limited cognitive abilities.</p> <p>Maniadis (2011), unpublished manuscript, retrieved online</p>
Increasing sum (exponential)	13-15 + three practice trials	C1: Standard game with No information about previous fractions of STOP moves at each node	Direct response method	26.6	2.9	2.25/0.45
			C2: Standard game with full information about previous fractions of STOP moves at each node		30.2	0.7	2.18/0.44
			C3: Standard game with partial information about previous fractions of STOP moves at each node (moves of		27.1	0.8	2.18/0.44

other player group only) C4: Modified game with No information about previous fractions of STOP moves at each node C5: Modified game with full information about previous fractions of STOP moves at each node				
The author investigated the effects of aggregate information about previous game outcomes (No information, full information and partial information about other player group only) on decision making in two different Centipede games (standard and modified). Contrary to the author's predictions, there was little evidence for the use of signalling to increase overall cooperation in the full information conditions. Instead, the article provided descriptive and tentative evidence that previous play decreased levels of cooperation. The modified Centipede game with a lower payoff difference between players at the final exit node of the game appeared to produce higher cooperation levels than the standard Centipede game, suggesting the subjects' preferences for equality and their sensitivity to small payoff differences. Overall, more testing sessions with aggregate information are needed to establish statistical significance.							
Mcintosh, Shogren, and Moravec (2009)
Increasing sum (exponential)	5 different Centipede games	C1: Tournament using ranking scheme based on total points earned	Strategy method	11.9	No information	No information
Increasing sum (exponential)/ Take-it-or-leave it	5 different Centipede games	C2: Tournament using ranking scheme based on tally reward system		38.1	No information	No information

After applying tallies, equivalent to:										
<div><div><div>1</div><div>2</div><div>3</div><div>4</div><div>5</div><div>6</div></div><div><div>1</div><div>0</div><div>1</div><div>0</div><div>1</div><div>0</div></div><div><div>0</div><div>1</div><div>0</div><div>1</div><div>0</div><div>1</div></div></div>										
Across two experiments, subjects completed five Centipede games of different payoff structures using the strategy method. Their strategies for the first game (exponential Centipede game) were subsequently entered into tournaments where they got paired with every other subject’s strategy twice (with different combinations of player roles). In the tournament of Experiment 1, the strategies got ranked according to the total number of points earned at the end. In the tournament of Experiment 2, “tallies” were awarded to the “winner” of each game (essentially turning the Centipede game into a constant-sum, Take-it-or-leave-it game). Winners of the tournament were determined by adding up all the tallies earned. In Experiment 1, only 11.9 percent of tournament games ended at the first decision node. After adding the tallies in Experiment 2, the tournament yielded an exit percentage of 38% at Node 1, showing that the binary incentive structure significantly decreased cooperation levels.										
McKelvey and Palfrey (1992)										
<div><div><div>1</div><div>2</div><div>3</div><div>4</div></div><div><div>6.40</div><div>1.60</div></div><div><div>0.40</div><div>0.20</div><div>1.60</div><div>0.80</div></div><div><div>0.10</div><div>0.80</div><div>0.40</div><div>3.20</div></div></div>				Increasing sum (exponential)	10	C1: 4 nodes, low stake	Direct response method	7.1	5.0	2.75/0.55
<div><div><div>1</div><div>2</div><div>3</div><div>4</div></div><div><div>25.60</div><div>6.40</div></div><div><div>1.60</div><div>0.80</div><div>6.40</div><div>3.20</div></div><div><div>0.40</div><div>3.20</div><div>1.60</div><div>12.80</div></div></div>						C2: 4 nodes, high stake		15.0	5.0	2.54/0.51
<div><div><div>1</div><div>2</div><div>3</div><div>4</div><div>5</div><div>6</div></div><div><div>25.60</div><div>6.40</div></div><div><div>0.40</div><div>0.20</div><div>1.60</div><div>0.80</div><div>6.40</div><div>3.20</div></div><div><div>0.10</div><div>0.80</div><div>0.40</div><div>3.20</div><div>1.60</div><div>12.80</div></div></div>						C3: 6 nodes low stake		0.7	1.4	4.10/0.59

The authors studied decision making in two Centipede games of different lengths. Additionally, they ran one testing session with a high payoff version of the shorter length game. In all versions of the game, the subjects deviated from the Nash equilibrium solution. Subjects stopped earlier in shorter games - particularly in the high payoff version. Furthermore, their play became less cooperative with increasing experience. The authors attributed the deviation from the game theoretic solution to incomplete information about the utilities involved in the game. They further assumed 5% of subjects to be motivated by altruistic preferences.

Murphy, Rapoport, and Parco (2004)

	Increasing sum (exponential)	90	C1: 21 genuine subjects	Direct response method	3.0	0.1	4.24/ 0.42
			C2: 15 genuine subjects, 6 cooperative robots		3.9	0.7	5.80/ 0.58
			C3: 18 genuine subjects, 3 non- cooperative robots		3.2	0.1	4.80/ 0.48
			C4: 15 genuine subjects, 6 non- cooperative robots		13.9	0.3	4.54/ 0.45

This experiment examined the influences of players with programmed strategies (robots) on cooperation levels in real subjects. Very cooperative robots were shown to increase overall cooperation, whereas the inclusion of non-cooperative players did not have a significant effect. Across all conditions, the researchers found individual differences in the natural disposition to cooperate and suggested that the play of altruistic players was not affected by the cooperation levels of their co-players.

Murphy, Rapoport, and Parco (2006)

t in sec's	0	1	5	10	20	30	40	45-ε	45	Increasing sum (exponential)	90	C1: Low payoff difference; 3 players	Direct response method (with simultaneous moves)	1.7	0	7.52/0.75
Winner	5	6	10	20	80	320	1280	2560-ε	0							
Loser 1	3	3	5	10	40	160	640	1280-ε	0							
Loser 2	3	3	5	10	40	160	640	1280-ε	0							

<table><tr><th>t in sec's</th><th>0</th><th>1</th><th>5</th><th>10</th><th>20</th><th>30</th><th>40</th><th>45-€</th><th>45</th></tr><tr><td>Winner</td><td>5</td><td>6</td><td>10</td><td>20</td><td>80</td><td>320</td><td>1280</td><td>2560- €</td><td>0</td></tr><tr><td>Loser 1</td><td>1</td><td>1</td><td>1</td><td>2</td><td>8</td><td>32</td><td>128</td><td>256-€</td><td>0</td></tr><tr><td>Loser 2</td><td>1</td><td>1</td><td>1</td><td>2</td><td>8</td><td>32</td><td>128</td><td>256-€</td><td>0</td></tr></table>										t in sec's	0	1	5	10	20	30	40	45-€	45	Winner	5	6	10	20	80	320	1280	2560- €	0	Loser 1	1	1	1	2	8	32	128	256-€	0	Loser 2	1	1	1	2	8	32	128	256-€	0			C2: High payoff difference; 3 players		3.3	0	5.52/ 0.55																																					
t in sec's	0	1	5	10	20	30	40	45-€	45																																																																																				
Winner	5	6	10	20	80	320	1280	2560- €	0																																																																																				
Loser 1	1	1	1	2	8	32	128	256-€	0																																																																																				
Loser 2	1	1	1	2	8	32	128	256-€	0																																																																																				
<table><tr><th>t in sec's</th><th>0</th><th>1</th><th>5</th><th>10</th><th>20</th><th>30</th><th>40</th><th>45-€</th><th>45</th></tr><tr><td>Winner</td><td>5</td><td>6</td><td>10</td><td>20</td><td>80</td><td>320</td><td>1280</td><td>2560- €</td><td>0</td></tr><tr><td>Loser 1</td><td>1</td><td>1</td><td>1</td><td>2</td><td>8</td><td>32</td><td>128</td><td>256-€</td><td>0</td></tr><tr><td>Loser 2</td><td>1</td><td>1</td><td>1</td><td>2</td><td>8</td><td>32</td><td>128</td><td>256-€</td><td>0</td></tr><tr><td>Loser 3</td><td>1</td><td>1</td><td>1</td><td>2</td><td>8</td><td>32</td><td>128</td><td>256-€</td><td>0</td></tr><tr><td>Loser 4</td><td>1</td><td>1</td><td>1</td><td>2</td><td>8</td><td>32</td><td>128</td><td>256-€</td><td>0</td></tr><tr><td>Loser 5</td><td>1</td><td>1</td><td>1</td><td>2</td><td>8</td><td>32</td><td>128</td><td>256-€</td><td>0</td></tr><tr><td>Loser 6</td><td>1</td><td>1</td><td>1</td><td>2</td><td>8</td><td>32</td><td>128</td><td>256-€</td><td>0</td></tr></table>										t in sec's	0	1	5	10	20	30	40	45-€	45	Winner	5	6	10	20	80	320	1280	2560- €	0	Loser 1	1	1	1	2	8	32	128	256-€	0	Loser 2	1	1	1	2	8	32	128	256-€	0	Loser 3	1	1	1	2	8	32	128	256-€	0	Loser 4	1	1	1	2	8	32	128	256-€	0	Loser 5	1	1	1	2	8	32	128	256-€	0	Loser 6	1	1	1	2	8	32	128	256-€	0	C3: High payoff difference; 7 players	43.6	0	2.51/ 0.25
t in sec's	0	1	5	10	20	30	40	45-€	45																																																																																				
Winner	5	6	10	20	80	320	1280	2560- €	0																																																																																				
Loser 1	1	1	1	2	8	32	128	256-€	0																																																																																				
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Loser 3	1	1	1	2	8	32	128	256-€	0																																																																																				
Loser 4	1	1	1	2	8	32	128	256-€	0																																																																																				
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Loser 6	1	1	1	2	8	32	128	256-€	0																																																																																				
The authors reported findings from an iterative real-time trust dilemma, which was based on the payoff function of exponentially increasing, multi-player Centipede games. The game did not have discrete decision nodes but was characterized by a continuous payoff function over a period of 45 seconds. The first person to stop the game, the "winner", received a payoff associated with the respective stop-time. The losers received a small proportion of the winner's payoff. All the scores reported here were calculated by dividing the raw data of exit times ranging between 0 and 44 seconds into nine bins of five seconds each. A tenth bin was added for games reaching the natural end (after 45 seconds) Each bin thus corresponds to a decision node of a regular Centipede game. The authors manipulated two factors: number of players (3 or 7) and loser's payoff (either 50% or 10% of the winner's payoff). Across all conditions, subjects stopped earlier with increasing experience in the game. Both larger payoff differences and larger group sizes accelerated the breakdown of trust.								Nachbar (2014), unpublished manuscript retrieved online

0	Increasing sum	60	N/A	Direct response method	36.3	0	2.76/ 0.17
								0							
								0							
								0							
								0							
10	1.5	2.2	3.3	5	110	170	250								
1	15	2.2	3.3	5	110	170	250								
1	1.5	22	3.3	5	1100	170	250								
1	1.5	2.2	33	5	110	1700	250								
1	1.5	2.2	3.3	50	110	170	2500								
This study investigated learning across 60 rounds in 5-player, high-stake Centipede games with randomly changing co-players. Whilst some learning effects were reported, no convergence towards equilibrium play was found. This was partly due to the high number of individuals, who consistently employed cooperative/altruistic strategies throughout the experiment.															

Nagel and Tang (1998)

Smaller choice	Possible higher choices of opponents	Payoff of A	Payoff of B	Sum
1	{2, 4, 6, 8, 10, 12, 14}	4	1	5
2	{3, 5, 7, 9, 11, 13}	2	5	7
3	{4, 6, 8, 10, 12, 14}	8	2	10
4	{5, 7, 9, 11, 13}	3	11	14
5	{6, 8, 10, 12, 14}	16	4	20
6	{7, 9, 11, 13}	6	22	28
7	{8, 10, 12, 14}	32	8	40
8	{9, 11, 13}	11	45	56
9	{10, 12, 14}	64	16	80
10	{11, 13}	22	90	112
11	{12, 14}	128	32	160
12	{13}	44	180	224
13	{14}	256	64	320

Strategically equivalent to:

Increasing sum
(exponential)

100

N/A

Strategy method
(variation),
game
presented
in normal
form

0.5

9.3

9.16/
0.65

This experiment tested for learning effects in a normal-form Centipede game over a period of 100 game iterations. No convergence towards equilibrium play was found. In earlier rounds, players seemed to be influenced by the immediately preceding moves. In later rounds, some fixed strategies were adopted. However, these were not in line with equilibrium play.

Palacios-Huerta and Volij (2009)

	Increasing sum (exponential)	1	C1: Chess players (field)	Direct response method	68.7	0	1.44/0.21
		1	C2: Students (field)		7.5	0	3.28/0.47
		10	C3: Chess players (lab)		72.5	0	1.39/0.20
		10	C4: Students (lab)		3.0	0.5	3.44/0.49
		10	C5: PA=chess player, PB=student (lab)		37.5	0	2.19/0.31
		10	C6: PA=student, PB=chess player (lab)		30	0	2.21/0.32

This article reported findings from Centipede studies using chess experts and students in field and laboratory settings. Overall, the chess players' decisions were much closer to the Nash equilibrium solution than the students'. Only a third of the chess players and none of the chess Grandmasters in the field study decided to continue at the first decision node. When matching students and chess players in lab experiments of the Centipede game, cooperation levels differed depending on the sample composition. Pure student samples were most cooperative; pure samples of chess players were least cooperative and mixed groups scored in between. The findings

indicated that decision making in the Centipede game was significantly influenced by cognitive abilities, and that individuals adapted their strategies depending on the type of co-player (and their expected reasoning skills).

Pulford, Colman, Lawrence, and Krockow (2016)

<p>80 50</p> <p>40 15 50 25 60 35 70 45 10 45 20 55 30 65 40 75</p>	Increasing sum (linear)	20	C1: Constant payoff difference; fixed pairing	Direct response method	13.3	9.6	4.63/0.51
	Increasing sum (linear)		C2: Constant payoff difference; random pairing		20.8	0.8	3.40/0.38
<p>76 28</p> <p>52 49 58 43 64 37 70 31 52 55 46 61 40 67 34 73</p>	Constant-sum		C3: Constant-sum; fixed pairing		17.1	0.4	3.10/0.34
	Constant-sum		C4: Constant-sum; random pairing		27.1	0	2.53/0.28
<p>74.5 33.5</p> <p>30.5 30 41.5 31 52.5 32 63.5 33 29.5 36 30.5 47 31.5 58 32.5 69</p>	Increasing sum (linear)		C5: Increasing payoff difference; fixed pairing		0.9	9.3	5.01/0.57
	Increasing sum (linear)		C6: Increasing payoff difference; random pairing		2.5	0	3.95/0.45
<p>84 78</p> <p>40 11.5 51 30.5 62 49.5 73 68.5 2 45.5 21 56.5 40 67.5 59 78.5</p>	Increasing sum (linear)		C7: Decreasing payoff differences; fixed pairing		17.3	30.0	5.72/0.64
	Increasing sum (linear)		C8: Decreasing payoff differences;		11.4	37.7	5.88/0.65

			random pairing
<p>Increasing sum (linear)</p>			C9: Constant payoff difference with strategy method, random pairing	Strategy method (variation)	23.3	1.3	3.47/0.39
<p>This study tested different theories explaining cooperation in the Centipede game. The authors compared decision making in games with subtly different payoff functions and found that cooperation was highest in Centipede games with linearly increasing payoffs where payoff differences between the two players decreased throughout the game. Comparing conditions of fixed pairing with the same co-player and conditions of random pairing, the former produced higher levels of cooperation. Play was found to be similarly cooperative when omitting sequential play by using the strategy method compared to standard conditions where the direct response method was used. Taken together, these findings suggest a strong impact of pro-social interests (including inequity-aversion), influences of fuzzy traces (mental gist representations), and reputation effects across games when repeatedly playing with the same co-player.</p>							
Pulford, Krockow, Colman, and Lawrence (2016)
<p>Increasing sum (exponential)</p>		20	C1: Individualistic SVO	Direct response method	1.0	18.0	6.72/0.75
			C2: Competitive SVO		1.5	7.5	5.98/0.66
			C3: Cooperative SVO		0	10.0	6.30/0.70
			C4: Neutral SVO		2.5	5.5	6.32/0.70
<p>Using framed task instructions, this study including two experiments induced different types of social value orientations (cooperative, competitive and individualistic) to test for influences of other-regarding preferences on decision making in the Centipede game. To keep this summary concise, on the results of Experiment 2 are reported. The manipulations produced significantly different cooperation levels, with competitively framed players stopping earlier than individualistically framed players. Additionally, a questionnaire measure of trait SVO showed interactions with the experimental manipulations. Interestingly, decision making in the neutral control condition was found to be significantly different from the individualistic condition. This refuted the game-theoretical assumption that randomly sampled subjects may hold selfish preferences by default.</p>							
Rapoport, Stein, Parco, and Nicholas (2003)							

[illegible]

	Increasing sum (exponential)	6 (change of co-player after three games)	N/A	Direct response method	1.3	9.2	8.02/0.73
<p>In this experiment, all subjects completed six Centipede games. Their co-players remained the same for the first three games. Then, random re-matching took place and they completed another three rounds with a different co-player. Overall, the results showed reliable deviations from the subgame perfect Nash equilibrium solution, with subjects exiting particularly late in the first round played with a new co-player (i.e., rounds 1 and 4). Cooperation then decreased in the following two rounds with the same co-player. These findings indicated that subjects treated the three rounds of repeated matching with the same co-player as supergames. The author suggested that sophisticated rationality and conscious deviations from the game-theoretic solution were used to establish a reciprocal relationship with the other player across rounds in order to ultimately maximize personal payoffs.</p>							
<p>Wang (2015), unpublished manuscript retrieved online</p>							
	Increasing sum	1 (Strategy method); then the strategies were matched across 15 game rounds	C1: Baseline game	Strategy method	No information	No information	No information
	Constant-sum		C2: Constant-sum game		No information	No information	No information
	Increasing sum		C3: “No-mutual benefit” game (low payoff for Player A at natural end)		No information	No information	No information
<p>This experiment explored rationality in the Centipede game which was defined as best response to the co-player’s expected beliefs and consequent decisions. Using a between-subjects design, the subjects completed one out of three Centipede games (baseline game with increasing sum and mutual benefits at final node; constant-sum game and increasing sum game with no mutual benefits at final node) using the strategy method. The strategy profiles were subsequently matched across 15 rounds of games. Afterwards, the subjects had to make predictions about their co-players’ strategy profiles. All treatment conditions showed reliable deviations from the Nash</p>							

equilibrium solution. The baseline condition produced the highest levels of cooperation, followed by the “No-mutual-benefit” condition and the constant-sum condition. When matching the actual decision strategies with the predicted strategies of the co-players to test for rationality, the results showed that subjects in the role of Player A overall were more rational than those in the role of Player B, and that the constant-sum game elicited higher levels of rationality than the other games.