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Jeannette Brosig-Koch, Timo Heinrich, and Christoph Helbach[1]

Exploring the Capability to Backward Induct – An Experimental Study with Children and Young Adults

Abstract

We investigate learning and the development of the capability to backward induct in children and young adults aged 6 to 23 under controlled laboratory conditions. The experimental design employs a modified version of the race game. As in the original game (see Burks et al., 2009, Dufwenberg et al., 2010, Gneezy et al., 2010, and Levitt et al., 2011), subjects need to apply backward induction in order to solve the games. We find that subjects' capability to backward induct improves with age, but that this process systematically differs across gender. Our repetition of the games provides insights into differences in learning between age groups and across gender.

JEL Classification: C72, J13, C91

Keywords: Backward induction; learning; age effects; experimental economics; children

July 2012

1 All University of Duisburg-Essen. – We benefited from the comments of conference participants in Chicago, Luxembourg, Lund, and Nuremberg. Furthermore, we thank the teachers at the participating schools for their help. Financial support by the Fritz Thyssen Foundation is gratefully acknowledged. – All correspondence to: Jeannette Brosig-Koch, Faculty of Economics and Business Administration, University of Duisburg-Essen, Universitätsstr. 12, 45117 Essen, Germany, E-Mail: jeannette.brosig-koch@ibes.uni-due.de.

1 Introduction

Dynamic decisions are of importance in many areas of daily life (e.g., in sequential negotiations, in health prevention, in making arrangements for retirement, or in investing in education). As long as one can assume that there is a last period, people need to apply backward induction in order to calculate their optimal decision. At least, backward induction is a fundamental assumption in modeling such decisions in economics. But are people capable to backward induct?

Several experimental studies have reported what appear to be failures of applying backward induction. For example, in centipede games very few subjects play the subgame-perfect equilibrium strategy suggested by game theory and end the game at the first node (see McKelvey and Palfrey, 1992, Fey, McKelvey, and Palfrey, 1996, Nagel and Tang, 1998, Parco et al., 2002, Rapoport et al., 2003, Bornstein et al., 2004). As this solution depends on common knowledge of selfishness and rationality, explanations such as the existence of social preferences or limited knowledge of rationality have been proposed. Focusing on the latter explanation, Palacios-Huerta and Volij (2009) attempt to vary "the 'closeness' to common knowledge of rationality" (p. 1620) by comparing the play of student subjects and chess players in the centipede game. In their laboratory experiment, 72.5 percent of games played by chess players facing other chess players end at the first node. When students face students, only 3.0 percent do so. Yet, if both groups of subjects are matched with each other, their behavior converges: When chess players move first, 37.5 percent of the games end immediately; when students move first, 30.0 percent do so.

Palacios-Huerta and Volij also conduct a field experiment where chess players face each other in the centipede game. Again, they observe a large share of equilibrium play: 68.7 percent of first-movers employ the equilibrium strategy. However, these results are in contrast to more recent observations made by Levitt et al. (2011). Replicating the field experiment of Palacios-Huerta and Volij, they find only 3.9 percent of chess players to end the game on the first move. Additionally, Levitt et al. study the chess players' performance in the race game. The equilibrium in this game can also be found by backward induction, but its game-theoretic solution is more robust than the solution of the centipede game. In the race game two players alternate in choosing numbers between 1 and an integer k. All chosen numbers are added up and the player that chooses a number that makes the sum equal to an integer m wins. Using this game has the advantage that the optimal strategy does not depend on beliefs about other players and, since it is a constant sum, winner-take-all game, it also does not depend on distributional or efficiency concerns. Some chess players in the study by Levitt et al. (2011) prove to be quite sophisticated in solving the race game with *k* equal to 9 or 10 and *m* equal to 100. But Levitt et al. observe no systematic relationship to the behavior in the centipede game. They conclude that the rather late stops in the centipede game are not driven by the subjects' inability to reason backwards.

Despite the conflicting results, two basic observations can be made: (i) a non-negligible share of people appears to be able to apply backward induction; (ii) in the centipede game the frequency of equilibrium play depends on information about the opponents.

In this study we build on observation (i) and ask how differences in the ability to apply backward induction evolve. We extend the previous research by focusing on the development of this capability among different age groups. In particular, using modified versions of the race game, we compare how these games are solved by children and young adults aged 6 to 23 years. Additionally, we study whether there are differences between these age groups regarding the improvement of their performance.

Observation (ii) underlines the importance of selecting an appropriate experimental design to isolate the influence on backward induction behavior. Because our focus is on the ability to backward induct, we follow Levitt et al. in choosing the race game as an experimental paradigm. Additionally, to increase comparability between age groups, we opt for a design in which all subjects face the same computerized opponent (that plays the equilibrium strategy if possible).

The race game has been introduced to behavioral research in studies by Burks et al. (2009), Dufwenberg et al. (2010) and Gneezy et al. (2010). Employing two race games with *k* equal to 3 and 4 and *m* equal to 14 and 16, respectively, Gneezy et al. study whether, and how fast, subjects learn to backward induct.[1] They observe that only after experiencing defeats subjects seem to apply this method. Dufwenberg et al. focus on learning transfers across games with *k* equal to 2 and *m* equal to 6 and 21. They report that experience with the shorter game improves performance in the longer one, though subjects seem to work "this analytic solution out in steps" (p. 141). Similar to the findings by Gneezy et al., the results suggest that cognitive limitations hinder subjects to backward induct right from their beginning. In fact, based on a sample of 1,000 trainee truckers, Burks et al. find a significantly positive relationship between performance in a race game (referred to as Hit15), IQ measured by a

[1] In their notation G(15, 3) and G(17, 4).

nonverbal IQ test (Raven's matrices), and a test of quantitative literacy. Their results also reveal that the ability to solve the race game is positively related to patience, to the willingness to take calculated risks, and to the truckers' perseverance on their jobs, among others. This relationship to other economically important behavioral traits and behavior in the field further emphasizes the value of finding out more about the capability to backward induct.

In recent years, the influence of age on decision-making has started to gain more and more attention in economic research. The focus of this research ranges from the endowment effect and individual risk attitudes (Harbaugh et al., 2001a, 2002, Dohmen et al., 2006, Sutter et al., 2011) over competitiveness (Bartling et al., 2012, Gneezy and Rustichini, 2004) bargaining behavior (Murnighan and Saxon, 1998, Hoffmann and Tee, 2006, Sutter and Kocher, 2007, Sutter, 2007), social preferences (Almås et al., 2010, Fehr et al., 2008), contributions made in public good games (Krause and Harbaugh, 2000), as well as the use of saving strategies (Otto et al., 2006) and reveal significant effects of age on behavior.

More closely related to our study, there is also some research on the development of cognitive skills with age in an economic context. Harbaugh et al. (2001b) test whether children exhibit rational choice behavior. They find that choices of 6th graders (about 11 years old on average) are as consistent as choices of undergraduates (about 21 years), while 2nd graders (about 7 years) decide more often inconsistently. Czermak et al. (2010) investigate the strategic behavior of 10 to 17 year olds in static two-person games. They observe no influence of age on the likelihood to be strategic. The results of both studies suggest that rational behavior develops early, but does not much change thereafter. Investigating the capability to backward induct we find some supportive evidence for this finding. Though, males and females seem to follow a different path of development. Interestingly, our re-analysis of gender specific data obtained in the study Harbaugh et al. (2001) reveals similar differences between males and females.[2]

The paper proceeds as follows. The next section presents the race games that were used in our study as well as the theoretical prediction. Section 3 describes our experimental design. The results are provided in section 4. Section 5 concludes.

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[2] We thank William Harbaugh for providing the data.

2 Games

To study the capability to backward induct, we employ six different race games $G(m, k)$ in which two players alternate in choosing numbers between 1 and (k =) 4. The player that chooses a number that makes the sum of all chosen numbers equal to m wins. The six games only vary regarding m, which takes the values 19, 3, 29, 8, 11 and 21, respectively.

The race game can be solved by backward induction. In order to reach a sum equal to m in her last move, player 1 needs to reach m-(k+1) on her second last move. This way player 2 has no chance to reach m on his last move. To be able to reach m-(k+1) on her second last move, player 1 needs to secure position m-2(k+1) on the move before, or, more generally, m-n(k+1) on her nth last move.[3] Accordingly, the first mover can win all race games except those where m is divisible by (k+1). This implies that our games require 0 to 5 steps of backward induction to be solved and that all of them can be won by the first mover.

3 Experimental design

The experiment was conducted with subjects of six different age groups. Subjects were recruited from an elementary school (with about 340 students) and a secondary school (with about 1,500 students) in the town of Fröndenberg and from the University of Duisburg-Essen (with about 37,000 students). All institutions are located in Germany's most populous state of North Rhine-Westphalia.[4]

In order to make the race game understandable to subjects from all age groups, we took great care in simplifying its exposition. After consulting several teachers, we opted for a purely graphical display of the games which was programmed in z-Tree (Fischbacher, 2007; see the screenshots in Figures 1 and 2 below). In addition, we used the following framing of the games: Subjects were informed that they are playing several games against a computer who tries to win the game.[5] They learned that the computer has hidden a treasure (the yellow square, see Figure 1) in a cave, but blocked the way from the cave's entrance to the treasure

[3] As Dufwenberg et al. (2010) and Levitt et al. (2011) point out, the race game does not require backward induction in a *strict* sense as a player does not need to solve for his opponent's optimal choice.

[4] The details of the education system in Germany vary by state. Generally, after primary school children can attend four types of secondary schools. Two types that offer degrees allowing to pursue different paths of vocational training (Hauptschule and Realschule), one type that aims at awarding the degree necessary for university admission (Gymnasium), and a fourth type that offers all types of degrees (Gesamtschule). Fröndenberg has only one secondary school which is of the latter type. Thus, selection effects through educational tracking are minimized.

[5] By playing against a computerized opponent, performance is comparable across all individual players (see, e.g., Johnson et al., 2002, McKinney and Van Huyck, 2006, Brosig and Reiß, 2007, and Burks et al., 2009, for similar approaches in sequential games).

with stones (the red squares). The number of stones varies across games. In order to win the game, they have to reach the treasure by removing the stones. The subject and the computer take turns in removing stones by dragging them into their respective box which holds up to four stones. After each turn, the stones in the box disappear. Whoever is able to place the treasure in his box, wins the game. In all games subjects are in the role of the first mover and, accordingly, can reach a winning position in the first move. If the computer cannot reach a winning position, it resorts to random play.

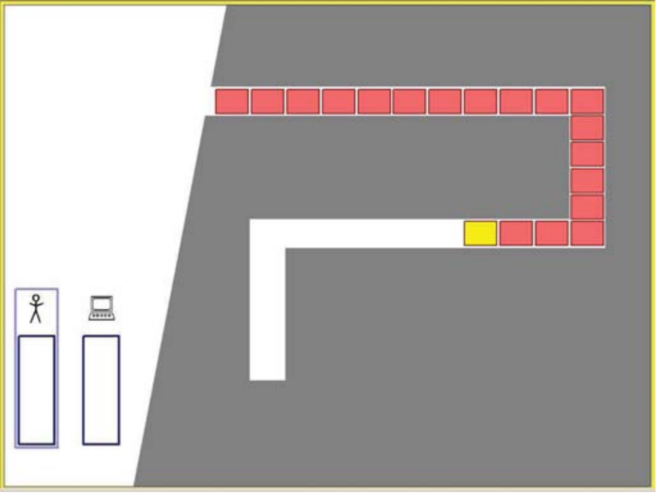

Figure 1: Graphical display of game $G(m=19, k=4)$

In order to get insights into the information subjects acquire to solve the game and to identify chance winnings, we initially hide the length of the game (see Johnson et al., 2002, for a similar procedure). That is, subjects were informed that their view on the cave is blocked by bushes (the green squares, see Figure 2). In order to take a stone, the bushes covering it need to be removed by clicking on a pair of scissors. On each click, starting from the cave's entrance, two adjacent bushes disappear. At their turn subjects can remove as many bushes as they like.

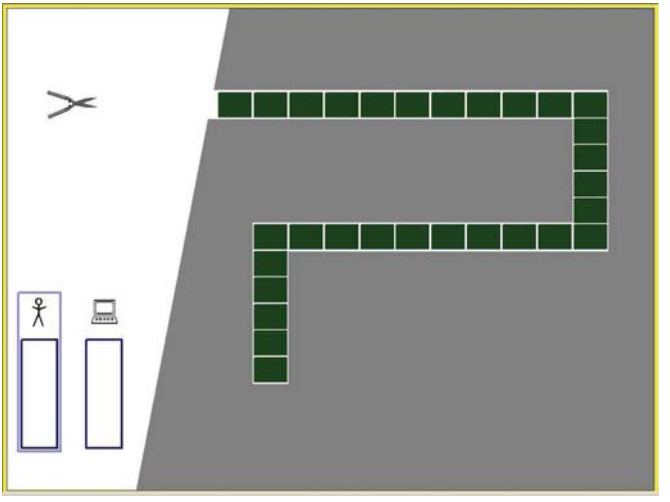

Figure 2: Graphical display of game with hidden length

At the beginning of the experiment, subjects received instructions which were read out aloud and were accompanied by a presentation and a video.[6] After the presentation, five control questions were read out aloud. Answers had to be given by dragging a ball into a “yes” or a “no” box. By using a similar elicitation procedure as in the games, we could also test whether subjects were able to handle the computer mouse (which was the case for all subjects). Having answered all questions correctly or being taught the correct answers, respectively, subjects played the six race games twice in identical order (but were left ignorant about the exact number of games to be played).[7] At the end of the experiment, 6th graders, 9th graders, and all university students had to fill out a questionnaire asking for personal characteristics such as risk attitudes and trust behavior. After filling out the questionnaire, subjects were paid off and received a fixed amount of money for each game won. We aimed at providing similar incentives for all subjects and, therefore, varied the amount across age groups. Students earned 5 Euro per game, 9th graders 4.40 Euro, 6th graders 2.70 Euro, 4th graders 1.80 Euro and 1st graders 1 Euro.[8]

[6] All instructions and questionnaires are included in Appendix A. The video is available upon request. Before the first session, we tested the design with 7 children aged 8 to 13 who showed no problems in understanding the game.

[7] Comparing these two series of games allows us to observe improvements in the performance. As we only repeat every game once, improvements are more likely due to additional steps of reasoning rather than chance and reinforcement learning. As the results by Gneezy et al. (2010) reveal, few subjects who have learned the winning strategy in G(m=14, k=3) are subsequently able to win G(m=16, k=4) on the first try.

[8] The incentives were set after consulting the school board of the respective school. Furthermore, we based the calculation on public pocket money recommendations for children in Germany.

In all age groups, subjects knew that their performance would be recorded anonymously (i.e., we used a double-blind procedure). Before the experiment, subjects received a card with a code name and were randomly assigned to a computer. At the end of the experiment subjects entered their code name and received the payment in a padded envelope marked with their code name from a person unaware of the amount it contained. At the schools the envelopes were handed out by the teachers and at the university by a student assistant not involved in the experiment. At both schools it was necessary to collect written consent from the students' parents. To preserve anonymity, teachers collected the forms and were carefully instructed to randomly select eligible students from their class as subjects.

At both schools, we ran two sessions within each age group with 15 subjects each. All these sessions were conducted at a computer lab of the secondary school. At the university, we ran six sessions with a total of 55 university students. All these sessions were conducted at the Essen Laboratory for Experimental Economics (elfe). University students were recruited via Orsee (Greiner, 2004) so that the share of economics students among subjects approximately matches the share of people who start studying economics in Germany from a given cohort. Our data set is summarized in Table 1.

Group	*N*	Female	Minimum Age	Maximum Age	Institution
Grade 1	30	67%	06 y 10 m	07 y 11 m	Elementary school
Grade 4	30	50%	09 y 10 m	11 y 08 m	Elementary school
Grade 6	30	47%	11 y 10 m	13 y 08 m	Secondary school
Grade 9	30	43%	14 y 11 m	16 y 11 m	Secondary school
University	55	51%	20 y 00 m	26 y 01 m	University

Table 1: Age groups

4 Results

For the analysis, we homogenized data sets among age groups.[9] That is, within each age group we selected the largest group with a common age range of 12 months. This was done in order to avoid potential biases of results due to repeaters, for example. The resulting data set is summarized in Table 2. Note that using the full sample does not alter our results qualitatively.

[9] In this case the threshold age between older and younger university students is set at the median age within this group. All data at individual level is included in Appendix B.

Group	N	Female	Minimum Age	Maximum Age
Grade 1	29	66%	06 y 10 m	07 y 09 m
Grade 4	28	50%	09 y 11 m	10 y 10 m
Grade 6	25	44%	11 y 10 m	12 y 09 m
Grade 9	24	38%	14 y 11 m	15 y 10 m
University young	21	57%	20 y 00 m	20 y 10 m
University old	19	50%	23 y 00 m	23 y 11 m

Table 2: Restricted data set

4.1 The effects of age

We first investigate the average number of games won by the different age groups in the first series of the six race games (i.e., in part 1). The results are illustrated in Figure 3. On average, subjects win 1.897 games in part 1 (and, not surprisingly, they are more likely to win a short game than to win a long game, see Figure 4). Looking for differences between age groups, we find that 1st graders perform significantly worse than all other age groups ($p < 0.016$, two-tailed exact Mann-Whitney-*U* test). Moreover, both groups of university students perform weakly significantly better than 4th and 9th graders ($0.058 < p < 0.098$). All other differences between age groups are not significant ($p > 0.123$).

One possible explanation for the different performance of 1st graders in part 1 might be that they are too young to understand the instructions. However, all except two 1st graders won the game $G(m=3, k=4)$, i.e. the second game, already in the first sequence of games.

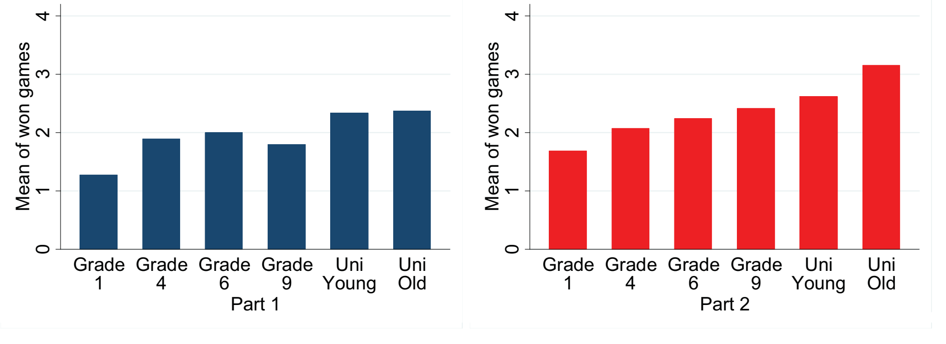

Figure 3: Average number of games won by age groups

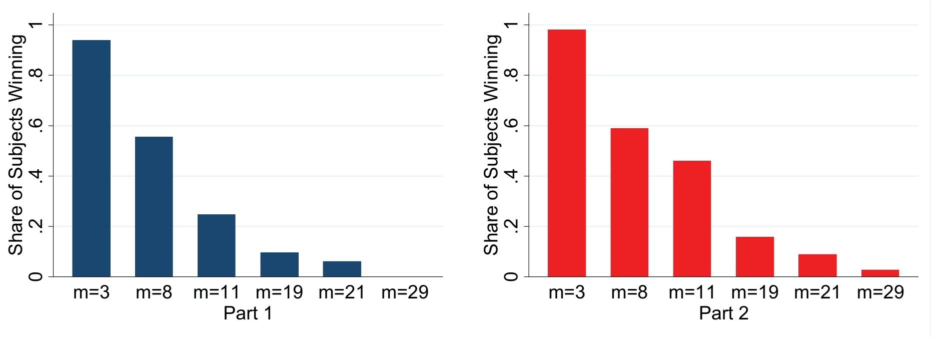

Figure 4: Share of subjects winning by game length

Comparing subjects' performance between the two series of race games, we observe a better performance in the second series for all grade levels, significantly so for 1st graders, 9th graders, and old university students ($p < 0.029$, two-tailed exact Wilcoxon signed rank tests). As a result, the number of games won on average increases to 2.301 in part 2. Now 1st graders no longer perform significantly worse than 4th graders ($p = 0.130$, two-tailed exact Mann-Whitney-*U* test) and 9th graders no longer perform significantly worse than young university students ($p = 0.561$).[10]

Our findings can be summarized as follows: First (and in line with previous findings), subjects have difficulties to solve the race games. Second, there is significant learning within age groups, though. This learning is particularly pronounced among those subjects who are, in part 1, significantly less able to solve the games than the subsequent age group. Third, learning among those subjects is that fast that, in the repetition of the games, they already 'catch up' to the level of the subsequent age group. Fourth, even within our oldest age group we still observe significant learning.

4.2 Revealing the treasure

Do the improvements of performance observed in part 2 imply that, in this part, subjects are better able to backward induct? One necessary (though, not sufficient) condition indicating that subjects apply backward induction is that they uncover the length of the game (i.e., remove the bushes in order to reveal the treasure) before their first move. Overall, 62.3 percent of subjects always reveal the treasure before playing a game in part 1. This share

[10] Interestingly, in a very recent study of the race game, Hawes et al. (2012) also find that subjects incrementally improve their performance rather than developing the optimal solution at once. They support this finding by both behavioral and fMRI data.

significantly increases to 82.2 percent in part 2 ($p = 0.000$, two-tailed exact McNemar test). Similar results apply if we focus on the average sum of games in which a subject reveals a treasure: this sum is significantly higher in the second series of games than in the first one ($p = 0.000$, two-tailed exact Wilcoxon signed rank test). Moreover, those subjects who win a game almost always reveal the treasure before playing it. Out of the 613 won games only 1.6 percent are won by a player who does not uncover the length of the game. In contrast, in 17.5 percent of the 1,139 lost games the length of the games is not uncovered before the first move.

Since uncovering the length of the game does not necessarily imply that subjects subsequently backward induct, we also test whether those who revealed the treasure perform significantly better than chance. In particular, we calculated the probability for chance winnings (based on the programmed computer play) for each game in the two parts. Comparing observed frequencies of winnings with the calculated probabilities we find that subjects perform significantly better in all games except the first instance of the longest game (i.e., game number 3; $p < 0.010$, two-tailed exact binomial test). This result still applies if the calculated probability is based on the additional assumption that subjects take the treasure as soon as they have the opportunity to do so ($p < 0.010$).[11]

To sum up, our findings on subjects' information acquisition and their performance after revealing the length of the games provide, at least, some support for the hypothesis that subjects apply backward induction to solve the games.

4.3 The role of gender

When aggregating over all age groups, male subjects perform significantly better than female subjects in both series of games ($p < 0.011$, two-tailed exact Mann-Whitney-U test). Differentiating between age groups and parts reveals that the significant differences are restricted to both, 4th graders and 6th graders, in the second series of race games ($p < 0.020$). Moreover, comparing the performance of subjects between the two parts of the experiment, we find (weakly) significant learning only for male 4th graders, female 9th graders, and female old students ($p = 0.016$, $p = 0.031$, and $p = 0.078$, respectively). The data is illustrated in Figure 5.

[11] Note that under the additional assumption the shortest game is not testable anymore as this game is won with certainty.

These results suggest a somewhat different development of the capability to solve the race game and to backward induct among males and females: Male and female subjects in our sample start off and end up at the same level of performance. However, males seem to acquire some skills that help to improve the play of the game earlier than females. This step of development appears to take place sometime between grades 1 and 4 for males and sometime between grades 6 and 9 for females.

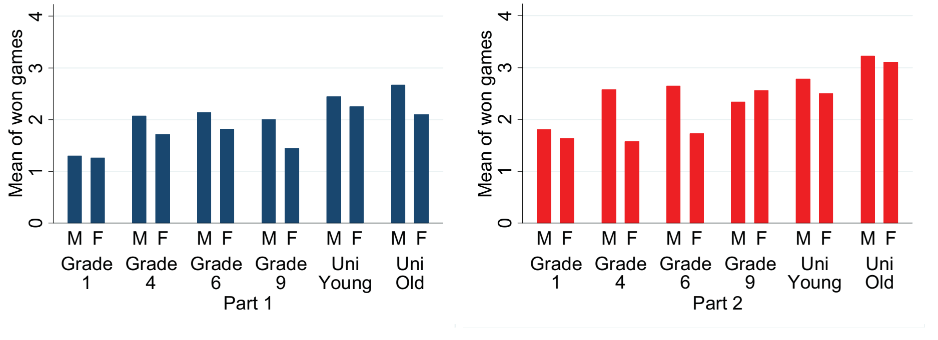

Figure 5: Average number of games won by male and female subjects.

To further assess the robustness of this result, we re-examine the data of Harbaugh et al. (2001b) focusing on gender differences. In their study 2nd graders, 6th graders and university students had to choose between consumption bundles in 11 different choice sets of which one was randomly selected to determine payoffs. Each choice set consisted of between 3 and 7 bundles differing in the number of bags of potato chips and boxes of fruit juice subjects could receive. Harbaugh et al. then check these choices for violations of the Generalized Axiom of Revealed Preference. Interestingly, the data reveal a pattern of gender differences that is similar to the one observed in our race games: While there are no significant gender differences in the number of inconsistent decisions for 2nd graders and university students ($p > 0.500$), male 6th graders decide more consistently than their female peers ($p = 0.020$).

4.4 Regression analysis

In order to control for confounding influences, we conducted three OLS-regressions with the number of games won by a subject as dependent variable. The first regression includes dummy variables for grades[12], gender, and a dummy indicating whether the subject revealed

[12] This specification captures non-linear age effects that are likely to occur especially between school students and university students due to selection.

the treasure before the first game or not. The second regression additionally includes a subject's school mark received in math and in German.[13] It is based on a data set that excludes all 1st graders since these subjects do not receive marks yet. The third regression additionally includes data from our ex-post questionnaire, i.e. a subject's patience, trust, fairness, and risk preferences. The data were elicited through questions similar to those employed by the German Socio-Economic Panel (a detailed description of variables is included in Appendix C). Since questionnaires were not filled in by 1st graders and 4th graders, the data set for the third regression is restricted to 6th graders, 9th graders, and university students. In all regressions 6th graders serve as the baseline category. The results of the three regressions are displayed in Table 3.[14]

	OLS - dependent variable: number of games won					
	(1)		(2)		(3)	
Grade 1	-1.899***	(0.617)				
Grade 4	-0.143	(0.559)	-0.255	(0.581)		
Grade 9	-0.306	(0.552)	-0.239	(0.573)	-0.264	(0.601)
Student (young)	0.233	(0.636)	0.080	(0.663)	0.094	(0.733)
Student (old)	0.991	(0.633)	0.936	(0.660)	0.894	(0.214)
Grade 1 x female	0.017	(0.583)				
Grade 4 x female	-1.475***	(0.561)	-1.194**	(0.591)		
Grade 6 x female	-1.084*	(0.598)	-0.982	(0.638)	-0.974	(0.681)
Grade 9 x female	-0.223	(0.625)	-0.160	(0.649)	-0.347	(0.685)
Student (young) x female	-0.219	(0.658)	-0.209	(0.686)	-0.148	(0.747)
Student (old) x female	-0.707	(0.680)	-0.760	(0.714)	-0.717	(0.781)
Reveal treasure	0.828***	(0.272)	0.955***	(0.315)	0.973**	(0.378)
Mark German			-0.041	(0.077)	-0.034	(0.092)
Mark math			0.188***	(0.063)	0.195**	(0.075)
Fairness					-0.394	(0.419)
Patience					-0.023	(0.075)
Risk					0.027	(0.086)
Trust					0.570*	(0.324)
Constant	4.253***	(0.432)	2.798***	(0.908)	1.303	(1.648)
Adj. R-squared	0.260		0.211		0.151	
N	146		116		88	

Standard errors are given in parentheses. * p<0.10, ** p<0.05, *** p<0.01.

Table 3: Regressions

[13] The marks were obtained from the school directly for pupils, while university students were asked about their last marks in the questionnaire. After consulting teachers at both schools grades were aligned to a common scale from 1 (poor) to 15 (very good).
[14] As we do not observe participants who win every game or no game at all, censoring does not need to be taken into account.

All three regressions support our previous interpretation. Revealing the treasure before the first game also positively influences the number of games won, while being female has – if at all – a (weakly) significantly negative effect in 4th and 6th grade. Controlling for school marks we additionally find that subjects who are better in math are more capable to solve the games and, accordingly, win more games. The inclusion of subjects' answers to the ex-post questionnaire reveals a weakly significantly positive relationship of trust to a subject's capability to solve the game. This somewhat surprising result is in line with previous research by Burks et al. (2009) who find a positive correlation between trust and IQ. Neither risk attitudes nor fairness preferences appear to be related to the number of games won.[15]

5 Conclusion

In this study we aim to shed light on the development of the capability to backward induct. We develop a graphical variant of the game that is suitable for children and consider the behavior of children and young adults in two series of race games. The observations confirm that, on average, subjects have difficulties to backward induct. But the results presented here reveal that the difficulties diminish with age. In particular, subjects are able to learn how to solve a race game. Differentiating between gender we find significant differences not only regarding the ability to backward induct, but also with respect to learning this ability. While there are no gender differences up to the 4th grade, male 4th graders significantly improve in solving the race game. Accordingly, we find some evidence for performance differences between males and females among 4th and 6th graders. Since there are no differences between males and females among 9th graders (and students), it seems that females caught up to males after the 6th grade. We also find evidence for this gender-specific path of development in the data obtained by Harbaugh et al. (2001b) who test whether children make rational choices about consumption goods. This suggests that similar cognitive abilities are responsible for rational choice behavior and backward induction. Note that our results are not at odds with observations made by Czermak et al. (2010) in static two-person games, who do not find any relationship between age and the level of strategic sophistication. As they study the behavior of 5th, 7th, 9th and 11th graders the differences can be attributed to the different age ranges under consideration.

Research in neuroscience seems to support our findings regarding gender differences insofar as it reports a different development of male and female brains (for an overview see, e.g.,

[15] Note that we obtain the same qualitative result using the unrestricted data set.

Lenroot and Giedd, 2006). For example, the decrease of subcortical gray regions (e.g. basal ganglia) during childhood is particularly pronounced among males (Giedd et al., 1996a, Rajapakse et al., 1996, Reiss et al., 1996). Moreover, hippocampal formation volume seems to increase with age for females while amygdala volume seems to increase with age for males (Giedd et al., 1996b). The findings raise the question whether females exhibit an earlier development of other important capabilities which develop later among males. Answering this question remains open for further research.

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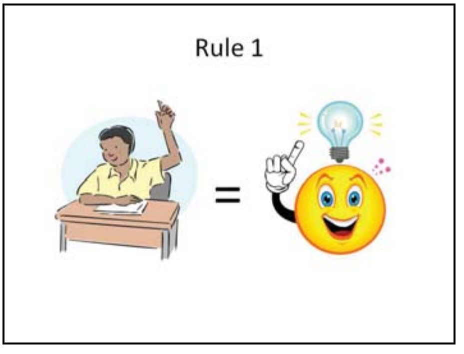
Appendix A: Instructions

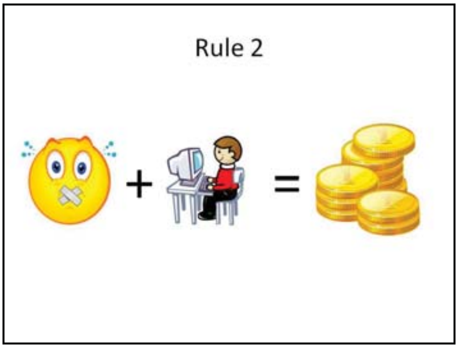
The following instructions were read aloud by the experimenter. They were accompanied by slides and a short video.

Hello and welcome! Today you are taking part in an experiment in which you will be able to earn money. How much money you will earn depends on your decisions.

Important: All your decisions are made anonymously. Nobody will be able to link the choices you made to your name. We will tell you in a moment what the experiment is about. First of all there are two important rules:



1. Signal us, if you do not understand something. We want you to have a perfect understanding of everything!

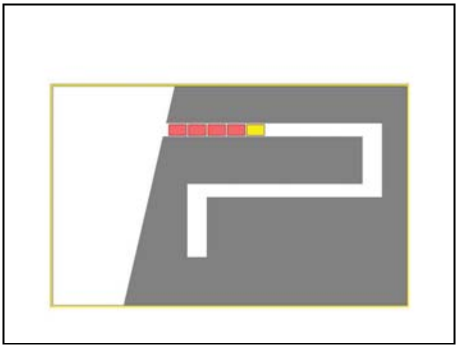


2. It is not allowed to talk to other participants. If you, however, talk to another participant you will be immediately excluded from this experiment. Consequently you will also earn no money in this case.

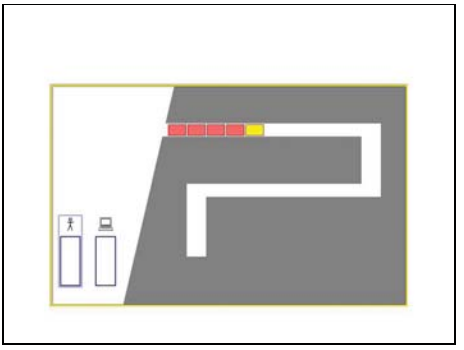
Now let's return to the rules of the game. Several times each of you will individually play a game against the computer. The more often you win against the computer, the more money you will earn. How does the game look like?

The computer challenges you. The goal of the game is to reach and collect a treasure.

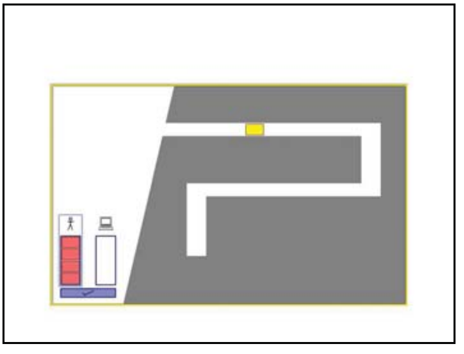
The treasure, which looks like a yellow square, has been buried by the computer in a cave, which has only one entry. You and the computer can reach the treasure only by using the entrance of the cave.



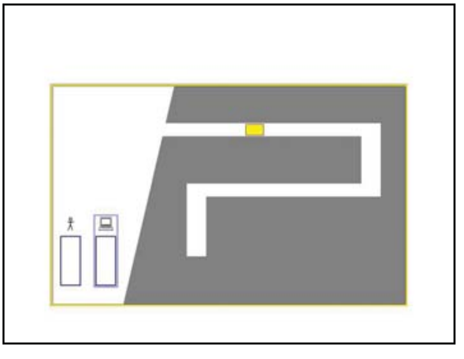
Unfortunately, the computer has blocked the passage from the entry to the treasure with one or more red stones. (This means that behind the treasure there are no more red stones but only air.) To reach the treasure you have to remove the red stones. The stones can only be removed by carrying them out through the entrance of the cave. This means that you and the computer can only move the stone, which is the closest to the entrance.



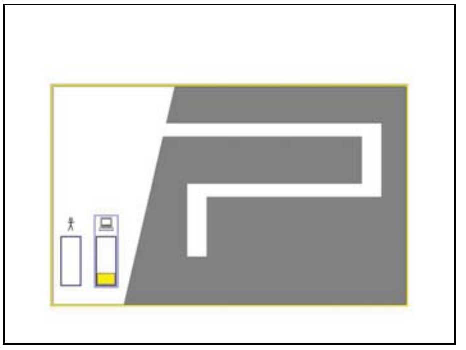
You can remove the stones by packing them into your box. This box (the blue rectangle on the left side) only fits one, two, three, or at most four stones.



By removing the stones you alternate with your rival, the computer.

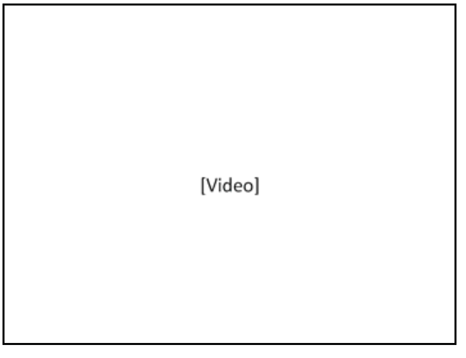


The computer can also remove stones and also has a box (the blue rectangle on the right side) that fits four stones at most.

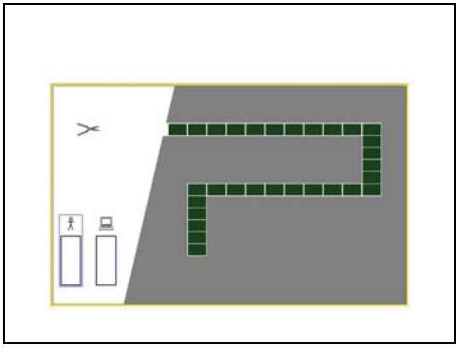


After every move the stones in your box and the computer's box disappear. The winner is the player who packs the treasure in his box first. In this game you are always the first who can pack stones into your box and remove them. Thereafter, it is the computer's turn. Same as you, the computer tries to win the game and to put the treasure into his box.

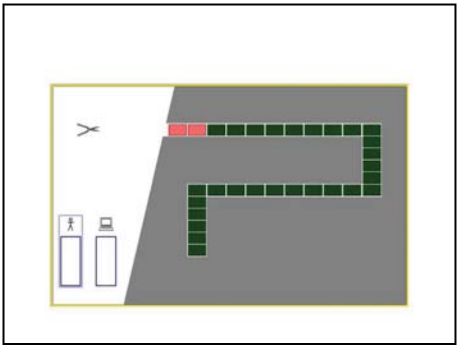
You can pick a stone by clicking on it with the mouse, holding the button and pulling the stone into your box. (If you have put more stones in your box than you wanted to, you can pull the stones back into the cave.) When there are as many stones in your box as you want to remove, you have to click on the blue checkmark button and the stones disappear. Then it is the computer's turn and you can observe how many stones the computer removes.



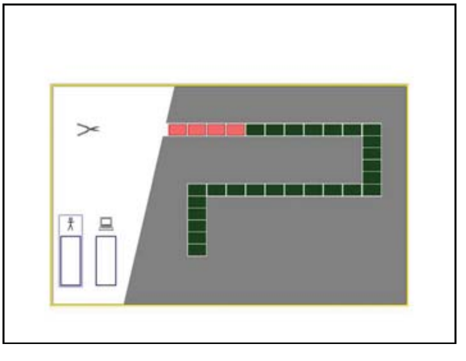
You take turns with the computer until one of you removes the treasure and wins. You can only win by packing the stone into your box and removing it. Same as you, the computer must remove at least one stone at each turn.



There is a special feature: After the computer has hidden the treasure it has blocked your view to the cave with bushes, that look like green squares. The computer knows what is hidden behind each green bush. If you want to see what is behind the green bushes as well, you just have to click on the hedge trimmer.



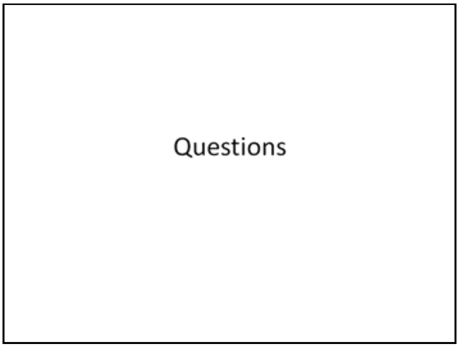
Starting from the entry of the cave you can remove two adjacent bushes by clicking on the hedge trimmer once.



In each move you can remove as many green bushes as you want. Behind every green bush there can be either a red stone, or nothing, or the treasure. As mentioned before, you play several games consecutively. These games differ from each other only in the number of red stones, blocking your way to the treasure. For each game you win you will receive 5 [amount depending on age group] Euro.

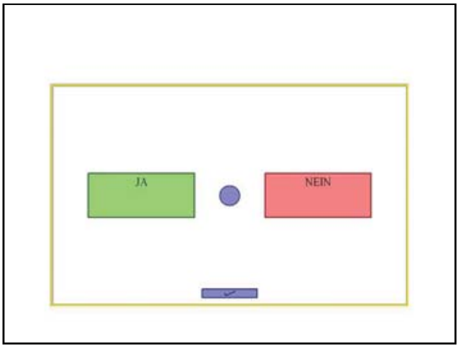
When you entered this room you received a card with your code name. Please keep it safe. At the end of the experiment you have to enter your code name in the computer. You also need your card to collect your payoff.

At the end of the experiment your respective payoffs will be calculated. After this the cash desk in the corridor outside the laboratory opens. There you can collect a closed envelope containing your payoff by showing your card. The cashier does not know what is inside these envelopes. Please collect your payoffs immediately after the experiment. [Payoff description of the instructions for university students.]

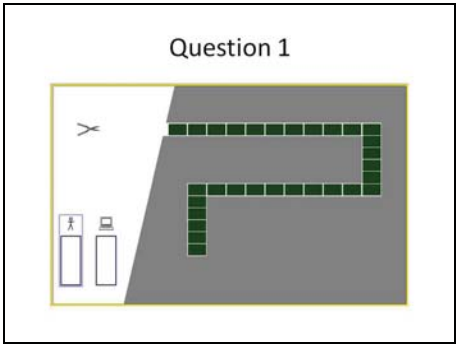


Questions:

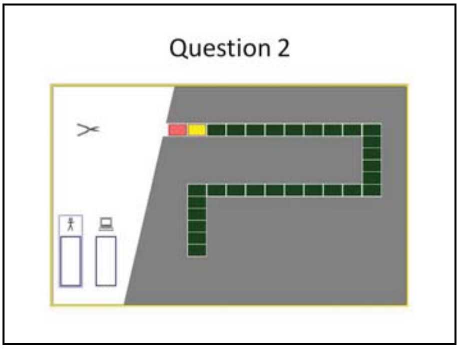
Before we start we will ask some questions so that we can help you better to understand the game.



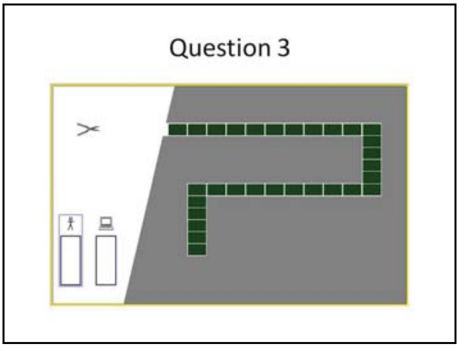
Please answer the questions with “Yes” or “No” by pulling the blue ball, which will appear in front of you on the monitor, into the green or the red area.



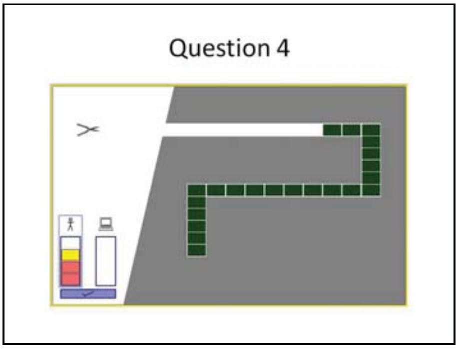
1) Please have a look at the following game. Does the computer know behind which green bush the treasure lies?



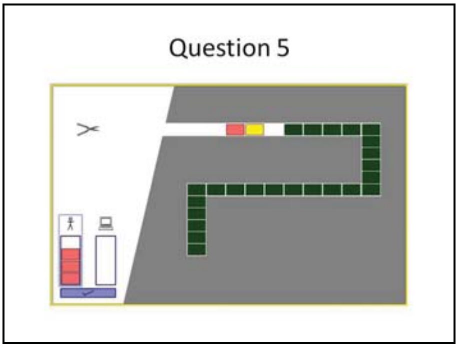
2) Please have a look at the following game. Do you see where the treasure is?



3) Please have a look at the following game. Are you allowed to remove all green bushes with the hedge trimmer now?



4) Please have a look at the following game. Is it correct, that the computer is winning the game?



5) Please have a look at the following game. You want to pack two stones into your box in order to win. Is this possible?

Appendix B: Data

ID	*Age (months)*	*Grade (12)*	*Grade (full)*	*Female*	*Wins (I)*	*Wins (II)*	*Mark math*	*Mark German*	*Fair*	*Patience*	*Risk*	*Trust*	*Reveal (1st game)*
1	247	14	14	1	2	3	10	13	7	2	2	0	1
2	308		15	1	3	4	13	13	1	8	2	0	1
3	240	14	14	1	2	3	13	12	7	6	3	0	0
4	262		14	0	3	3	6	12	8	9	2	0	1
5	250	14	14	0	2	2	10	13	6	5	3	1	1
6	293		15	1	1	2	12	12	2	4	2	0	0
7	249	14	14	1	3	3	8	12	1	2	2	0	1
8	290		15	1	2	3	8	14	2	9	2	0	0
9	313		15	1	3	3	8	10	8	5	3	1	1
10	249	14	14	0	3	3	9	6	7	2	2	1	1
11	257		14	1	2	5	9	13	7	1	3	1	1
12	295		15	0	3	3	15	8	8	3	3	0	1
13	311		15	0	3	3	7	12	8	9	4	1	0
14	312		15	0	2	3	10	12	6	9	3	1	0
15	246	14	14	1	3	3	12	13	4	3	3	0	1
16	269		14	0	4	3	12	12	1	3	3	1	1
17	263		14	1	3	3	11	14	7	10	4	1	0
18	274		15	0	3	3	13	12	2	7	2	0	0
19	253		14	0	3	4	12	10	4	2	3	1	1
20	261		14	0	2	3	13	8	2	2	2	0	1
21	241	14	14	1	2	4	10	12	7	4	3	0	1
22	240	14	14	0	1	2	11	10	6	1	3	1	1
23	272		15	0	3	2	10	10	7	4	3	1	0
24	243	14	14	1	3	3	12	12	7	3	3	0	0
25	127	4	4	1	2	1	11	11					1
26	124	4	4	1	3	3	11	11					1
27	123	4	4	1	1	1	8	8					0
28	126	4	4	1	2	3	11	14					1
29	121	4	4	1	3	2	8	11					1
30	130	4	4	1	1	1	5	8					1
31	126	4	4	1	2	1	5	11					0
32	126	4	4	1	1	1	11	11					1
33	121	4	4	0	2	2	11	11					1
34	126	4	4	0	1	2	11	11					0
35	123	4	4	0	2	2	8	11					0
36	126	4	4	0	1	1	11	11					1
37	118		4	0	2	3	11	11					0
38	121	4	4	0	4	4	14	11					1
39	121	4	4	0	2	3	8	5					0
40	129	4	4	1	1	1	8	11					1
41	126	4	4	1	3	2	8	11					1
42	140		4	1	1	1	8	11					1
43	130	4	4	1	1	1	5	11					1
44	128	4	4	1	1	2	11	14					0
45	120	4	4	1	1	2	11	11					1
46	119	4	4	1	2	1	8	8					1
47	128	4	4	0	1	2	11	11					0
48	121	4	4	0	2	3	8	11					1
49	127	4	4	0	3	3	11	8					1
50	129	4	4	0	1	2	5	8					1
51	128	4	4	0	3	3	11	11					1
52	127	4	4	0	2	3	11	11					1
53	129	4	4	0	3	3	11	14					1
54	120	4	4	0	2	3	11	11					0
55	92	1	1	1	2	3							1
56	83	1	1	1	2	1							0
57	85	1	1	1	1	2							0
58	82	1	1	1	1	2							1
59	91	1	1	1	2	3							1
60	93	1	1	1	2	1							1
61	91	1	1	1	2	2							1
62	90	1	1	1	1	1							1
63	92	1	1	0	1	2							1
64	84	1	1	0	1	1							1
65	88	1	1	0	2	1							1
66	86	1	1	0	2	2							1
67	82	1	1	1	1	3							0
68	95		1	1	1	1							0
69	82	1	1	1	2	1							1
70	83	1	1	1	1	1							1

ID	*Age (months)*	*Grade (12)*	*Grade (full)*	*Female*	*Wins (I)*	*Wins (II)*	*Mark math*	*Mark German*	*Fair*	*Patience*	*Risk*	*Trust*	*Reveal (1st game)*
71	82	1	1	1	1	2							1
72	82	1	1	1	1	2							0
73	93	1	1	1	1	2							1
74	90	1	1	1	1	1							1
75	89	1	1	1	1	1							1
76	89	1	1	1	1	2							0
77	93	1	1	0	1	1							0
78	88	1	1	1	1	0							0
79	84	1	1	0	1	1							1
80	82	1	1	0	1	3							1
81	90	1	1	0	2	2							1
82	93	1	1	0	1	3							1
83	91	1	1	0	1	2							1
84	84	1	1	1	0	1							0
85	186	9	9	0	2	2	10	8	8	1	3	1	0
86	194		9	1	1	2	10	12	6	2	3	1	1
87	189	9	9	1	2	4	8	12	5	4	3	0	0
88	183	9	9	0	3	0	14	12	3	9	3	1	1
89	190	9	9	0	3	3	6	10	5	7	4	1	1
90	184	9	9	1	1	1	10	8	5	5	3	1	0
91	190	9	9	0	2	3	12	10	3	4	4	1	0
92	185	9	9	1	3	3	14	10	7	1	4	1	0
93	186	9	9	0	0	1	10	10	3	7	3	1	0
94	188	9	9	0	2	3	8	10	7	3	2	1	0
95	191		9	1	0	3	10	8	5	5	2	0	0
96	186	9	9	0	2	3	6	12	3	6	4	1	1
97	196		9	1	2	3	12	10	4	8	2	1	1
98	203		9	0	4	3	12	8	2	9	3	1	1
99	188	9	9	0	2	2	10	6	8	7	2	1	1
100	188	9	9	1	0	2	4	6	5	6	4	1	0
101	184	9	9	1	2	2	8	8	7	4	3	1	1
102	142	6	6	1	2	3	11	11	2	8	3	1	1
103	157		6	1	1	1	5	8	4	9	3	1	0
104	148	6	6	0	2	1	5	5	3	6	3	1	1
105	152	6	6	0	2	2	8	11	4	0	3	1	1
106	150	6	6	1	1	2	8	11	4	8	4	1	1
107	151	6	6	0	3	4	2	5	4	8	4	1	0
108	153	6	6	1	1	2	8		3	8	3	1	0
109	148	6	6	0	2	3	8	8	3	8	3	1	1
110	147	6	6	1	1	1	5	8	3	7	3	1	0
111	159		6	1	0	1	5	8	8	3	3	1	0
112	153	6	6	1	2	1	11	11	5	7	2	1	0
113	145	6	6	1	2	1	8	11	6	9	3	1	1
114	144	6	6	1	3	2	11	11	4	7	3	1	1
115	152	6	6	1	2	3	14	11	1	5	3	1	0
116	164		6	1	1	2	2	5	6	7	3	1	1
117	187	9	9	0	1	1	4	10	6	5	3	0	0
118	180	9	9	1	1	2	4	6	1	5	4	0	1
119	182	9	9	0	3	4	12	10	3	6	3	1	0
120	184	9	9	1	1	3	10	12	6	9	2	1	0
121	179	9	9	0	2	3	10	6	6	6	3	0	0
122	189	9	9	0	2	3	10	12	6	4	3	1	1
123	181	9	9	0	0	2	10	10	3	6	2	0	0
124	190	9	9	0	3	3	8	10	5	2	3	1	1
125	194		9	1	1	2	4	4	5	4	3	0	0
126	193		9	0	0	1	6	4	8	5	3	0	0
127	180	9	9	0	3	2	8	12	8	2	2	1	1
128	190	9	9	1	1	2	12	12	7	9	3	1	0
129	185	9	9	1	2	4	10	12	9	1	3	1	1
130	152	6	6	1	2	2	11	11	5	8	3	1	0
131	143	6	6	0	4	4	14	11	7	9	3	1	1
132	148	6	6	1	2	1	11	11	5	8	3	0	0
133	157		6	0	4	2	11	8	6	5	4	1	1
134	144	6	6	1	2	1	2	8	6	4	3	0	1
135	151	6	6	0	2	2	11	11	6	5	3	1	1
136	143	6	6	0	2	2	11	14	7	5	3	1	0
137	145	6	6	0	1	1	11	14	3	3	2	1	0
138	152	6	6	0	0	3	8	11	7	5	3	1	0
139	155		6	0	2	3	14	11	8	1	2	0	1
140	149	6	6	0	2	3	11	11	8	2	3	1	1
141	145	6	6	0	2	3	8	11	2	9	3	1	1
142	148	6	6	0	3	3	11	8	6	6	3	1	1
143	144	6	6	0	3	2	14	11	1	3	3	0	1

ID	*Age (months)*	*Grade (12)*	*Grade (full)*	*Female*	*Wins (I)*	*Wins (II)*	*Mark math*	*Mark German*	*Fair*	*Patience*	*Risk*	*Trust*	*Reveal (1st game)*
144	144	6	6	0	2	4	11	11	4	5	3	1	0
145	242	14	14	1	3	2	10	13	7	2	2	1	1
146	246	14	14	0	3	3	8	10	4	5	3	0	1
147	246	14	14	1	1	2	11	12	3	5	2	1	1
148	243	14	14	0	3	3	12	12	7	2	2	1	1
149	240	14	14	1	2	2	10	13	3	9	2	1	1
150	242	14	14	1	1	2	12	9	2	8	2	1	0
151	240	14	14	0	3	4	14	15	7	5	3	1	1
152	244	14	14	0	3	3	8	13	8	2	2	1	1
153	245	14	14	0	1	1	10	12	5	2	3	1	0
154	241	14	14	1	2	1	10	10	8	3	2	0	0
155	248	14	14	0	3	4	11	8	7	2	3	0	1
156	242	14	14	1	3	2	10	11	4	2	3	1	0
157	278	15	15	1	1	1	6	15	3	6	2	0	1
158	277	15	15	1	2	3	10	9	9	9	3	1	1
159	286	15	15	0	2	3	10	12	7	4	2	0	1
160	283	15	15	1	1	1	10	13	2	0	2	0	0
161	287	15	15	0	3	6	9	8	8	4	2	0	1
162	276	15	15	1	3	4	12	11	2	2	3	1	1
163	281	15	15	0	3	3	8	10	2	1	2	0	1
164	283	15	15	1	3	3	12	15	1	3	3	1	1
165	284	15	15	1	2	5	10	13	2	5	3	1	1
166	280	15	15	1	1	3	6	13	5	2	3	0	1
167	277	15	15	1	2	3	12	13	3	9	3	0	1
168	277	15	15	0	3	5	10	13	3	2	3	0	1
169	276	15	15	1	2	5	15	12	2	1	3	1	1
170	277	15	15	0	1	1	11	8	8	2	3	1	1
171	287	15	15	0	3	3	10	14	5	2	2	1	1
172	276	15	15	0	4	3	10	12	3	4	3	1	0
173	281	15	15	0	3	4	10	10	8	7	4	1	1
174	287	15	15	0	2	1	11	12	7	3	3	1	0
175	282	15	15	1	4	3	12	12	2	8	2	0	0

Appendix C: Description of variables

Variable	Description
ID	Unique subject number
Age (months)	Age in months
Grade 1	Is subject from grade 1 (restricted sample), 1 = yes, 0 = no
Grade 4	Is subject from grade 4 (restricted sample), 1 = yes, 0 = no
Grade 6	Is subject from grade 6 (restricted sample), 1 = yes, 0 = no
Grade 9	Is subject from grade 9 (restricted sample), 1 = yes, 0 = no
Student (young)	Is subject a "young" university student (restricted sample), 1 = yes, 0 = no
Student (old)	Is subject an "old" university student (restricted sample), 1 = yes, 0 = no
Grade (12)	Grade when the sample is restricted to a maximum age range of 12 months at every level, 1 = grade 1, 4 = grade 4, 6 = grade 6, 9 = grade 9, 14 = young university student, 15 = old university student
Grade (full)	Grade without sample restriction, 1 = grade 1, 4 = grade 4, 6 = grade 6, 9 = grade 9, 14 = young university student, 15 = old university student
Female	Gender, 1 = female, 0 = male
Reveal treasure	Did the subject reveal the treasure before the very first move in game one? 1 = yes, 0 = no
Mark German	School mark in German on a scale from 1 = very poor to 15 = very good (for university students the last school mark is used)
Mark math	School mark in math on a scale from 1 = very poor to 15 = very good (for university students the last school mark is used)
Fairness	Reply to the question 'Do you think most people…' on a scale form 0 = '… would exploit you if they were given the chance' to 1 = '… would try to treat you in a fair way'.
Patience	Reply to the question 'How do you see yourself: Are you normally an impatient person or do you usually exercise patience?' on a scale from 0 = 'very impatient' to 10 = 'very patient'.
Risk	Reply to the question 'How do you see yourself: Do you normally take risks or try to avoid them?' on a scale from 0 = 'do not take risks at all' to 10 = 'take a lot of risks'.
Trust	Reply to the question 'What is your opinion on the following statement: In general, on can trust people' on a scale from 1 = 'fully disagree' to 4 = 'fully agree'.
Wins (1)	Number of games a subject wins in part 1
Wins (2)	Number of games a subject wins in part 2