Strategic sophistication of adolescents – Evidence from experimental normal-form games[*]

Simon Czermak
University of Innsbruck

Francesco Feri
University of Innsbruck

Daniela Rützler
University of Innsbruck

Matthias Sutter[#]

University of Innsbruck and University of Gothenburg and IZA Bonn

Abstract

We examine the strategic sophistication of adolescents, aged 10 to 17 years, in experimental normal-form games. Besides making choices, subjects have to state their first- and second-order beliefs. We find that the ability to predict others' real behavior and to best reply to own beliefs is dependent both on the complexity of a decision (dominant strategy for the player or his opponent, number of available strategies) and on certain individual characteristics such as math grades, the ability to play chess or the existence of siblings. Using a mixture model we estimate the probability distribution over eight different strategic and non-strategic types. We find that older subjects are more likely to eliminate dominated strategies, and that subjects with good math grades are more strategic.

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[#] Corresponding author. Address: Department of Public Finance, University of Innsbruck, Universitaetsstrasse 15, A-6020 Innsbruck, Austria. e-mail: matthias.sutter@uibk.ac.at

1. Introduction

Standard game theory is the fundamental pillar of research in economics, and more generally in the social sciences, since it provides a tool to analyze strategic interaction, like interaction in markets, bargaining, or in social dilemma situations. In this framework strategic sophistication refers to the extent to which behavior in strategic situations reflects a decision maker's attempt to predict the others' decisions by taking their incentives into account. In real life agents with a high level of strategic sophistication can benefit from this ability in many situations of economic and social interaction. Not only adult decision makers, already children and teenagers in their daily routine very frequently face situations of strategic interaction. Just imagine a child which is playing at the playground and wants to persuade other children to engage in his favorite game or a teenager who wants to convince his parents to raise his pocket money.

In numerous previous studies it has been shown that strategic sophistication of adult decision makers is often limited (see, e.g., Stahl and Wilson, 1994, 1995; Haruvy et al., 1999; Costa-Gomes et al., 2001; Weizsäcker, 2003; Bhatt and Camerer, 2005; Crawford and Iriberri, 2007; Costa-Gomes and Weizsäcker, 2008; Fehr et al., 2012; Rey-Biel, 2009; Sutter et al., 2010a). In summary, the experimentally observed limitations of strategic sophistication are due to the absence of considerations of other players' incentives and rationality (Costa-Gomes et al., 2001, Weizsäcker, 2003) or due to the failure to best respond to own stated beliefs. For instance, Costa-Gomes and Weizsäcker (2008) report such a failure to happen in about fifty percent of cases. While the literature on strategic sophistication has developed models to explain this surprisingly large degree of bounded rationality (see Costa-Gomes and Crawford, 2006, or Costa-Gomes and Weizsäcker, 2008, for a discussion of models and new approaches), it has remained silent on the development of strategic sophistication with age.

The literature on the decision making of children and teenagers has been pioneered mainly by Bill Harbaugh and Kate Krause and they have shown that in straightforward bargaining games children are able to employ simple forms of strategic considerations. This becomes particularly clear when comparing children's behavior in ultimatum and dictator games, where for strategic reasons (i.e., fear of rejection) offers are higher in the ultimatum than the dictator game (see Harbaugh et al., 2003a).[1] While it seems beyond doubt that children and adolescents are able to make strategic inferences and act accordingly in simple economic games, the existing literature on the decision making of children and adolescents has not studied the extent of strategic sophistication (including not only an examination of choices, but also of first- as well as second-order beliefs) in childhood and adolescence. In a survey of simple bargaining experiments Camerer (2003, p. 66) notes that in ultimatum and dictator games children are "*closer* to the self-interest prediction of game theory than virtually any adult population". It is an open question whether this statement applies also more generally to strategic sophistication in normal form games, and in particular when subjects do not only have to make decisions (as in the games surveyed in Camerer, 2003), but are also asked to state beliefs about their opponent's choices and beliefs. Providing evidence to address this question is the main purpose of this paper.

In their study about strategic sophistication of teams Sutter et al. (2010a) find that different game characteristics like the complexity of a game, the equality of payoffs, or the risk of a strategy have an influence on the probability of the combination of a Nash first order belief with a Nash decision (also called "Nash consistency"). The identification of determinants of rational behavior of children definitely is of great interest for the literature on decision making of children and teenagers, as it provides insights about the roots of strategic behavior. Thus, in addition to the examination of the relevance of different game characteristics this paper includes an analysis of the influence of certain personal characteristics (like gender or grades) on rational beliefs and decisions in experimental normal form games. Detailed research about the strategic sophistication of children and adolescents furthermore is of great practical importance as young family members have a considerable and growing influence on household decision making (see McNeal , 1992; Dauphin et al., 2008). Insights about the roots of strategic behavior in early life could be the basis to develop educational actions supporting the development of strategic abilities.

In the experiment reported here, we let 196 adolescents, aged 10 to 17 years, make decisions in 18 different normal-form games that have been designed by Costa-Gomes et al. (2001) and used in Sutter et al. (2010a) to study strategic sophistication. We find that adolescents play the Nash strategy in about 45% of all cases. This relative frequency of equilibrium play is well in the range of 40% to 50% which is the typical finding in previous studies with adults (e.g.,

[1] Several other papers study the behavior of children and teenagers in simple interactive games, like public goods games (Harbaugh and Krause, 2000), trust games (Harbaugh et al., 2003b; Sutter and Kocher, 2007), or ultimatum games (Murnighan and Saxon, 1998; Sutter 2007).

Costa-Gomes and Weizsäcker, 2008; Sutter et al., 2010). As in Sutter et al. (2010a) we elicited first order (about the opponent's choice), and second order (about the opponent's first order belief) point beliefs. Eliciting higher-order beliefs allows us to examine not only the decision maker's consistency (where consistency means that choices are a best reply to first-order beliefs), but also the opponent's expected consistency, i.e. how subjects perceive the rationality of their opponents by checking whether first-order beliefs are best responses to second-order beliefs. In about 60% of cases our subjects choose a best response to their own first-order belief. This is slightly higher than what is observed with university students (Costa-Gomes and Weizsäcker, 2008; Sutter et al., 2010a). The expected consistency of opponents (by matching first- and second-order beliefs) is at a lower level of around 50%. The analysis of the determinants of consistency reveals that a dominant strategy for the player (opponent player) has a positive effect on our players' consistency (opponent's expected consistency). Students with better grades in mathematics are more likely to state first order beliefs which are a best reply to their own second order beliefs. Interestingly, the ability to being able to play chess has a negative impact on the probability to predict another's actual choices and first order beliefs (in other words - to state correct first- and second- order beliefs). Applying the mixture model of Costa-Gomes et al. (2001), we find that the majority of adolescents can be classified as non-strategic decision makers and the modal type is a non-strategic *optimistic* type (which plays the strategy that maximizes the maximum possible payoff). While we do not find a significant effect of age on the share of subjects classified as belonging to any of five different types of strategic decision making, we find that the elimination of dominated strategies becomes more likely with increasing age. Hence, detecting dominance relationships gets more frequent with older subjects. It is also interesting to note that girls are significantly more likely to eliminate dominated strategies than boys. We also find a relation between math grades and strategic decision making. Subjects with better math grades are more likely to be classified as strategic.

The rest of the paper is organized as follows: In section 2 we present the experimental design. Section 3 reports the experimental results and section 4 concludes the paper.

2. Experimental design

Our experimental design is based on the 18 normal-form games that were already used by Costa-Gomes et al. (2001) and Sutter et al. (2010a) to study strategic sophistication (see

Figure 1). There are 10 "**D**"-games in which one player has a strictly dominant strategy and 8 "**ND**"-games in which no player has a dominant strategy. In all games there is a unique pure Nash equilibrium that is Pareto-dominated by another strategy combination of row and column players. The games can also be classified according to the number of rounds of iterated pure-strategy dominance that players need to identify the equilibrium strategy. This refers to a game's complexity. In **D**-games the number of rounds a player requires to reach his own equilibrium choice is either 1 or 2, while in **ND**-games the corresponding number of rounds may be 2, 3 or infinite. Figure 1 indicates all games' types, complexities and the order with which the specific games were presented to participants.[4] The total of 18 games includes 8 pairs of isomorphic games that are identical for row and column players except for transformation of player roles and small, uniform payoff shifts.

Figure 1 about here

Each game was played only once and in each game subjects had to make three decisions in the following sequence:[5]

- **Choice**: For each given game each player had to choose one of the available strategies.
- **First-order belief (FOB)**: Subjects had to state their belief about the opponent's action.

  Second-order belief (SOB): Subjects were asked for their belief about the opponent's first-order belief.

Our subjects didn't get any feedback before all subjects had taken the total sum of 54 decisions. This is in line with the experimental design of Costa Gomes et al. (2001) and Sutter et al. (2010a) and was done with the aim to suppress learning and reputation formation.

In order to make incentives not only for choices, but also for higher order beliefs as salient as possible, we introduced a payment rule which in principle was already used in Sutter et al. (2010a). After all 54 decisions were taken by all experimental participants each subject was asked to draw a card from a deck of cards showing numbers from 1 to 18. The drawn number determined the game that was relevant for payment. In a next step the subject received full information about his/her own and the opponent's choice, first- and second-order

[4] This information can be found in the upper left and right corner of each game in Figure 1. The order of games in the experiment is indicated by "game # x", with x $\in$ {1, ..., 18}. (D) refers to **D**-games and (ND) refers to **ND**-games. Numbers in the brackets indicate a game's complexity for the row and column player, where [xR, yR] denotes the number of rounds needed for row (x) and column player (y).

[5] Games were presented to all participants in the same order as in Costa-Gomes et al. (2001) and Sutter et al. (2010) in a way that they saw themselves as a row player. The transformation of the column players' perspective didn't have any influence on the characteristics of the games and was intended to avoid any influence of the kind of presentation on behavior.

belief in the particular game. A second card to be drawn by a subject then determined whether choices (card A), first-order beliefs (card B) or second-order beliefs (card C) were paid.

Payments in the experiment were made contingent on the age of participants, calibrated on the average weekly pocket money. Based on survey data from the respective school, we knew that subjects aged 14 to 17 years (grades 9 and 11) receive on average slightly more than twice as much weekly pocket money as subjects aged 10 to 13 years (grades 5 and 7). Accordingly we scaled the payoffs in the following way. If a subject was paid for his/her choice, we paid 20 Euro-Cents per experimental point in grades 9 and 11, and we paid 10 Euro-Cents per point in grades 5 and 7. If subjects were paid for their first-order or second-order belief 9th graders and 11th graders received 10 Euros if their belief was correct, while 5th and 7th graders got 5 Euros for a correct belief, but zero otherwise. Note that all subjects received a show up fee, which was 4 Euros in grades 9 and 11, and 2 Euros in grades 5 and 7.

In the study of Sutter et al. (2010a) point beliefs instead of probability distributions were elicited. While this fact has considerable advantages in its practical applicability and thus guarantees a better understanding of the experimental instructions by the participants it contains certain difficulties in the analysis of a player's consistency. Nevertheless also the elicitation of probability distributions has problems with checking consistency when first and second order beliefs are involved (for a detailed description of these problems see Sutter et al., 2010a). Explaining the concept of a probability distribution and asking adolescents of age 10 to 17 to express their beliefs in an incentive compatible payment scheme like the quadratic scoring rule would have been extremely demanding for teenagers. Given the circumstance that both belief elicitation methods involve problems with the analysis of consistency and the fact that the game design we used has a relatively high number of decisions (54) we opted for eliciting point beliefs in order to keep the duration of the experiment shorter.

The experiment was run at the "Öffentliches Gymnasium der Franziskaner Hall", a public high school located 5 km east of Innsbruck, the capital of the state of Tyrol in Austria. This school teaches children in 8 different grades, in Anglo-Saxon terminology grades 5 to 12. We conducted the experiment in two classes each in 5th grade (10- to 11-year olds), 7th grade (12- to 13-year olds), 9th grade (14- to 15-year olds), and 11th grade (16- to 17-year olds). The sessions in both classes of a given grade were always run simultaneously in two separate rooms in order to avoid any potential dissemination of information. Students were never matched within their own class, but with one student from the other class. This procedure was common knowledge. Subjects were also informed that the identities would be kept strictly confidential toward other participants. In order to guarantee also anonymity within a class, we used sliding walls between subjects so that they could not observe other subjects' decisions.

Each session was started with an extensive description and training of the game (see supplementary material). Questions were answered in private. Before the start of the experiment, each participant had to answer a control questionnaire that checked the understanding of how decisions or beliefs mapped into payoffs. Five subjects (out of 196 in the beginning) did not answer all questions correctly. They are excluded in the following, yielding 191 subjects for the subsequent analysis. The experiment itself was run with paper and pen. We handed out the three decision sheets for each game (for choices, first- and second-order beliefs) game by game. That means that subjects had to make all three decisions for a particular game before proceeding to the next game. In total, each session lasted 2.5 hours. The average earnings were about 7 Euros for subjects in 5th and 7th grade, and 14 Euros for those in 9th and 11th grade. Our incentives can be considered as pretty salient because the average earnings were slightly higher than the average weekly pocket money of around 5 Euros for 10- to 13-year-olds, and 13 Euros for 14- to 17-year-olds.

3. Experimental results[7]

3.1. The influence of age on the strategic sophistication of adolescents

3.1.1 Frequency of „picking Nash" plotted against the complexity of decisions

Table 1 reports in the upper panel the relative frequencies for different types of own choices, in the middle and lower panel for different types of first-order, respectively second-order, beliefs. The first column considers all 18 games, while columns two and three present separate data for ***D***-games and ***ND***-games. We denote decisions that imply the strategy that leads to the Nash-equilibrium by "Nash", decisions that imply the strategy that would yield an outcome that Pareto-dominates the Nash-equilibrium by "Pareto" and decisions implying other strategies by "Other".

[7] All analyses presented in the results section are based on pooled data of row and column players. This is justified since there are 16 isomorphic games in the set of 18 games and all decision tasks were presented in a way that players saw themselves as row players. Note that all results reported here would also go through if we concentrated only on the 16 isomorphic games.

Table 1 about here

We note that on average Nash is played in 45% of cases. As becomes clear from Table 1 the relative frequency of playing Nash is, in the aggregate, roughly the same in all four grades in which we ran the experiment.[8] Not surprisingly, the relative frequency of Nash is clearly higher in ***D***-games (62%) than in ***ND***-games (24%). Looking at first- and second-order beliefs we note that the relative frequency of the Nash strategy is about 10 percentage points smaller according to beliefs than with actual play.[9]

Table 2 and Table 3 about here

Table 2 and Table 3 show how the level of a game's complexity affects choices and beliefs. Our comparisons in Table 2 are based on an analysis of Sutter et al. (2010a) in which a game's complexity is defined by the type of an underlying game and the required rounds of iterated pure-strategy dominance to identify the equilibrium choice. It reports the frequencies of chosen strategies in five different categories: ***D***-games with either one or two rounds of iterated pure-strategy dominance and ***ND***-games with either two, three or an infinite number of rounds. The first column in the upper panel shows that in games with a dominant strategy, players having a dominant strategy play Nash on average in 85% of cases. The likelihood of playing Nash is drastically reduced once a decision maker has no longer a dominant strategy (see the four right most columns in Table 2). The middle and lower panel of Table 2 refer to first- and second-order beliefs. While Nash remains on average at or above 80% in the first column, the other columns show that Nash is considerably less often expected (both in first- and second-order beliefs) than actually played. Table 3 is based on an analysis of Costa-Gomes et al. (2001) and illustrates different complexity levels a little bit more detailed by additionally considering the number of available strategies (for row and column players).

[8] If we assumed that subjects took their decisions randomly, the expected relative frequency of observing Nash equilibrium choices, first order beliefs or second order beliefs would be 43%. A comparison of the distribution of actually observed relative frequencies of playing Nash – based on individual level – and the distribution of theoretically expected ones in case of random play reveals that decisions are significantly different from random, though (Kolmogorov-Smirnov one sample test, $p < 0.01$).

[9] This pattern is consistent with a model of noisy introspection by Goeree and Holt (2004) in which they predict more noise – and hence less equilibrium play – with higher-order beliefs than with actual play.

When we check for significant differences between the different age groups we don't find strong results or clear patterns in both tables. At the same time the relative frequencies of Nash choices are close to values that were observed in previous studies in experiments with grown ups[11]. This observation is a strong indicator that strategic sophistication is already very well developed at an age of 10 years and remains more or less constant in subsequent years of age. We summarize the findings in this subsection as follows:

Result 1: Overall, the equilibrium strategy is chosen in about 45% of cases. First- and second-order beliefs of equilibrium play are significantly less frequent by roughly 10 percentage points. The relative frequency of playing Nash decreases with a game's complexity, i.e., the number of rounds of iterated pure-strategy dominance needed to identify the equilibrium. The share of equilibrium play and expected equilibrium play (Nash first and second order beliefs) remains more or less constant between the age of 10 and 17 years.

3.1.2 Frequency of consistent choices and beliefs

Based on the consistency analysis of Sutter et al. (2010a) we define a player's "*own consistency*" as the relative frequency of choices that are a best reply to her own first-order beliefs and the "*opponent's expected consistency*" as the relative frequency with which a player's first-order beliefs are a best reply to her second-order beliefs. Standard game theory would always predict a special case of consistency which is a combination of Nash choices and Nash beliefs[12]. This game theoretically consistent behavior is denoted Nash-consistency (Nash-CON) and analyzed in Table 5 together with a second special case of consistency which appeared in our data (and in the data of Sutter et al., 2010a) very frequently. This second type of consistency is defined as "Maximum-consistency" (Max-CON) and implies that a player's choice and first-order belief yields the maximum available payoff for the player (in the case of "own consistency") or that the combination of first- and second- order beliefs yields the maximum payoff for the opponent player (in the case of "opponent's expected consistency"). It is an important feature of the games we use that Nash-CON never coincides with Max-CON.

[11] Sutter et al. (2010) for example find an average share of equilibrium play of roughly 41 % for their grown up individuals, which is even a lower value than we have found in our experiments for an aggregate of all adolescent age groups

[12] In such a case an experimental participant would play Nash and expect the opponent to play Nash as well (own consistency) or would have a Nash first order belief in combination with a Nash second order belief (opponent's expected consistency)

As can be seen from Table 4 the frequency of best replies in the aggregate of all games lies between 60.85% and 64.44% when we analyze the players' "own consistency" and between 50.99% and 55.98% when we analyze the players' "opponent's expected consistency". [13] Thus the frequency of the "opponent's expected consistency" is (significantly[14]) lower than the frequency of the "own consistency". At the same time the "own consistency" is always higher in **D**-games than in **ND**-games, hinting at the influence of dominant strategies on consistent behavior.

Table 4 and Table 5 about here

For our players' "own consistency" as well as "opponent's expected consistency" we can see that Nash-CON is much more frequent in ***D***-games than in the ***ND***-games ($p < 0.05$, two-sided Wilcoxon signed rank tests).[16] As in the general case of consistency (described in the previous paragraph and in Table 4) the share of Nash-CON is higher in the category "own consistency" than in the category "opponent's expected consistency". At the same time Max-CON is observed in roughly 40% of all cases, indicating that subjects are pretty optimistic (by expecting the highest possible payoffs from their combination of choices and first-order beliefs). Again there are almost no significant differences with respect to consistency when we compare our different teenage age groups. A comparison with the results of Sutter et al. (2010a) with individual grown ups reveals an interesting relationship. While the share of "opponent's expected consistencies" is much smaller than the share of "own consistencies" in all our teenage age groups, the data of Sutter et al. (2010a) report a reversed pattern with grown ups – namely a higher share of "opponent's expected consistencies" in comparison to "own consistencies". This difference in behavior could be the result of higher "step-level reasoning abilities" of adult decision makers (for an introduction in step-level reasoning models see Stahl and Wilson (1994) and Stahl and Wilson (1995)).

We summarize the findings in this subsection as follows:

[13] Comparisons of theoretically expected relative frequencies of being consistent in the case of random play and actually observed relative frequencies of being consistent show that the null-hypothesis of randomness in consistency needs to be rejected ($p < 0.01$; both for own consistency and the opponent's expected consistency; Kolmogorov-Smirnov one-sample tests).

[14] $p < 0.05$, two-sided Wilcoxon-signed rank tests for all pairwise comparisons.

[16] Comparisons of the theoretically expected distribution of the relative frequencies of being Nash-CON in the case of random play and the actually observed distribution show that the null-hypothesis of randomness in Nash-consistency needs to be rejected ($p < 0.05$; both for own Nash-consistency and the opponent's expected Nash-consistency; Kolmogorov-Smirnov one-sample tests).

*Result 2: Choices are a best reply to first-order beliefs in more than 60% of cases, while first-order beliefs are a best reply to second-order beliefs in a significantly lower number of cases (less than 56%) . Most of the time, consistent choices and beliefs are of the Max-CON type, meaning that subjects expect the maximal payoffs. Nash-consistency (of playing and expecting the opponent to play Nash) is less frequent with 16% on average (all age groups aggregated), and more likely in **D**-games than in **ND**-games. We observe no significant differences between different age groups.*

3.2. The determinants of correct beliefs and consistent decisions

In this subsection we analyze the impact of potential influencing factors on correct beliefs and consistent decisions. With regard to beliefs we distinguish between a correct first order belief (a subject correctly predicts the choice of the player he is matched with) and a correct second order belief (a subject correctly predicts the other's first order belief). In line with our definition of consistent decisions in the previous subsection we analyze determinants of a player's "*own consistency*" and the "*opponent's expected consistency*". From a questionnaire we know if a certain participant has the ability to play chess, whether this person has siblings or not and his/her grades in mathematics and german (native language) from the annual school report of the foregone year[17]. Table 6 reports the results of a probit estimation[18] of correct first order beliefs on the factors "ability to play chess", "math grade", "german grade", "existence of siblings" and six other factors which are explained in the following: The variable "dominant strategy" considers the existence of a dominant strategy for the player herself, "opponent dominant strategy" the existence of a dominant strategy for the opponent player, the next three independent variables ("7th grade", "9th grade", "11th grade") are dummies for the different grades that were included in our experiment (with 5th graders as the benchmark) and the variable "# of other's strategies" simply includes the total number of available strategies to the opponent player.

Table 6 about here

[17] Due to time constraints we were not able to collect questionnaire data from eleven 7th graders. Because of this reason our probit estimations in Table 6 - 9 (which include questionnaire data as independent variables) are based only on a pool of 180 subjects (45 in 5th grade, 41 in 7th grade, 52 in 9th grade, 42 in 11th grade).

[18] In our probit estimations (Tables 6-9) standard errors are clustered on the decision maker, since each decision maker had to make decisions in all 18 games.

Our analysis in Table 6 shows no significant influence of our different age groups on correct first order beliefs but reveals some other interesting effects. It is not surprising that the existence of a dominant strategy for the opponent player raises the probability of a correct first order belief, but quite remarkable that a dominant strategy for a player herself and the ability to play chess lowers the probability of correct first order beliefs. We assume that both factors increase the frequency of strategically profound first order beliefs which are not reflected in the other's real decision behavior. While for grades and the existence of siblings we don't find a significant influence, a higher number of strategies available to the opponent player leads to a significant lower probability of a correct first order belief (which is quite plausible, as with an increasing number of options available the likelihood to have a correct first order belief by chance becomes lower).

Table 7 about here

Table 7 contains a similar probit regression with the major difference that determinants of correct second order beliefs are analyzed. In this probit regression we basically include the same factors which were already used in Table 6, but exchange the variable "# of other's strategies" with a variable indicating the number of available strategies to the player himself ("# of strategies"). This becomes necessary as a player's second order belief is directly related to his own choice. We find that a dominant decision for the player himself leads to a higher probability of correct second order beliefs while the existence of a dominant decision for the opponent player has no impact at all. Again the ability of playing chess seems to be contra-productive in predicting other players' real decisions (in this case second order beliefs). At the same time our analysis shows that the existence of siblings has a significantly positive influence on correct second order beliefs. This observation might be an indicator that interaction with other children (siblings) is positively correlated to a good knowledge about other's expectations and beliefs. An increasing number of available strategies again decreases the probability of correct beliefs. Finally we can observe an age effect showing a tendency that older adolescents have higher abilities in predicting other players' beliefs[19].

[19] As can be seen from Table 7 the dummies for 7th graders and 11th graders are significant with positive coefficients (while the coefficient for 11th graders is higher than the coefficient for 7th graders). An exceptional case in the observed age trend are 9th graders (the dummy for this age group doesn't show a significant impact on the probability of correct second order beliefs compared to 5th graders).

Sutter et al. (2010a) study determinants of Nash-consistent behavior arguing that this game theoretically perfect consistency describes the prediction of standard game theory. As can be seen from the previous subsection we observe Nash-consistent decisions only in 16 % of all cases while consistent decisions appeared in far more than 50% of all cases. In the next subsection we present an estimation of the frequency of player types for our teenage age groups showing a very small and insignificant fraction of "equilibrium player types" (which are defined by Nash-consistent behavior; see Table 10). Mainly the low appearance of Nash-consistent decision making of children and adolescents induced us to focus in this paper on determinants of consistent decision making instead of Nash-consistent decision making.

Table 8 about here

The probit estimation in Table 8 analyzes the influence of various factors on a player's "*own consistency*". Beside the independent variables which were already used in Table 6 and Table 7 we additionally include the variable "# of game results" which is defined by the number of possible game results ("number of strategies for player A" x "number of strategies for player B") for each game. The estimation shows that our players' "own consistency" is mainly influenced by the complexity of a certain game. While a dominant strategy for the player leads to a significantly higher likelihood of "own consistency" the estimation reveals a significant but reversed effect of a dominant strategy for the opponent player. Given the circumstance that our experimental participants were stating an opponent's dominant strategy as their first- order belief in more than 86% of all cases (see Table 2) this result indicates a lack of basic strategic ability. Many participants were able to detect an opponent's dominant strategy when being asked for their first order belief, but unable to integrate this insight into their own decision making process by choosing a best reply. All other independent variables in Table 8 have no significant impact on "own consistency".

Table 9 about here

In Table 9 we present a probit regression in which we use the same independent variables as in the previous regression (Table 8), but take the "*opponent's expected consistency*" as the dependent variable. Same as in the case of a player's "own consistency" we find that the “opponent’s expected consistency” is significantly influenced by the existence of dominant strategies. Our results show that a dominant strategy for the opponent makes a consistent expectation more likely, whereas the existence of a dominant strategy for the player has an opposite effect by reducing the likelihood of consistent expectations. Additionally we can observe significant effects related to our age groups in which the probability of “expected consistency” is significantly higher with 7th graders and 9th graders (compared to 5th graders). Finally our analysis in Table 9 finds a significant influence of the math grade[21], whereas children and adolescents with better grades state consistent expectations with a lower probability.

Result 3: The probability of correct first order beliefs is significantly affected by the existence of dominant strategies, by the opponent’s number of available strategies and by the ability to play chess. A dominant strategy for the opponent player makes a correct first order belief more probable, whereas the existence of a dominant strategy for the player himself, a higher number of available strategies for the opponent player and the ability to play chess make a correct first order belief less probable. Related to second order beliefs a dominant strategy for the player, the belonging to the 7th graders’ or 11th graders’ age groups and the existence of siblings have a significant positive effect on correct beliefs, whereas in the case of a higher number of available strategies for the player and the ability to play chess the effect is significant, but negative.

Result 4: The probability of a player’s “own consistency” is significantly higher when the player has a dominant strategy and significantly lower when his opponent has a dominant strategy. In the case of a player’s “opponent’s expected consistency” the effects of (a player’s resp. an opponent player’s) dominant strategies are still significant, but reversed. Additionally the belonging to the 7th and 9th graders’ age groups and better grades in mathematics have a significantly positive effect on the probability of the “opponent’s expected consistency”.

3.3. Estimation of strategic and non-strategic types

In the following we present a maximum likelihood error-rate analysis of players’ choices following the framework of Costa-Gomes et al. (2001). It is a mixture model in which each player’s type is drawn from a common prior distribution over eight types and where the type

[21] Note that the Austrian grading system defines grades by assigning numbers from 1 to 5, whereas better performances are rewarded with “lower numbers”.

is assumed to be constant for all 18 games. The eight different types can be classified into non-strategic and strategic types and are defined as follows:[22]

Non-strategic types: (1) An *altruistic* type makes an attempt to maximize the sum of both players' payoffs, implicitly assuming that the opponent is also *altruistic* (see Costa-Gomes et al., 2001). Note that *efficiency-loving* would probably be a more appropriate term for such a type. Hence, we will call this type *altruistic/efficiency-loving*. (2) A *pessimistic* type plays maximin, thus is taking choices that secure him the best of all worst outcomes. (3) An *optimistic* type chooses the strategy that maximizes the maximum possible payoff, thus ignoring the incentives of the opponent player. As noted by Costa-Gomes et al. (2001), it is impossible to distinguish an *optimistic* type from a *naïve* type in our 18 games. A *naïve* type assigns equal probabilities to the opponent's strategies and best responds to this naïve belief. While a *naïve* type might reflect strategic decision making with diffuse beliefs, Costa-Gomes et al. (2001) describe *naive* types as non-strategic. We follow their approach, but talk about *optimistic* types, which are non-strategic for sure.

Strategic types: (4) Type *L2* is choosing a best response to *optimistic* types. (5) Type *D1* plays best reply to a uniform prior over the opponent's remaining strategies after applying one step of deleting strategies that are dominated by pure strategies. (6) Type *D2* goes one step further in deleting dominated strategies. After applying two steps of deleting dominated strategies he chooses a best reply to the opponent's remaining strategies. (7) An *equilibrium* type takes equilibrium choices (which are unique in our games). (8) Choices of a *sophisticated* type are based on the actually observed distribution of strategies in the experiment's subject pool. A player of this type takes this distribution as a probability distribution for his opponent's choice and plays best reply to this information.

For the estimation of the mixture model let $i = 1, \dots, N$ index the different players, let $k = 1, \dots, K$ index our types, and let c = 2, 3, or 4 be the number of a player's possible decisions in a given game. We assume that a type-k player normally makes type k's decision, but in each game he makes an error with probability $\varepsilon_k \in [0,1]$, type k's *error rate*, in which case he makes each of his c decisions with probability $1/c$. For a type-k player, the probability of type k's decision is then $1-\frac{(c-1)}{c}\varepsilon_k$. So the probability of any single non-type k decision

[22] We follow Costa-Gomes et al. (2001) in the selection of types to be considered. As they indicate, the definition of types is largely based on earlier work by Stahl and Wilson (1994, 1995). Note that Costa-Gomes et al. (2001) introduce nine types. However, naïve and optimistic types cannot be distinguished in the games used in Costa-Gomes et al. (2001) and here.

is $\frac{\varepsilon_k}{c}$. We assume errors are independently and identically distributed across games and players.

The likelihood function can be constructed as follows. Let T^c denote the total number of games in which players have c decisions. In our design we have T^2 =11, T^3 =6, and T^4 =1. Then let x_k^{ic} denote the number of player i's decisions that equal type k's in games in which he has c decisions with $x_k^i = (x_k^{i2}, x_k^{i3}, x_k^{i4})$, $x^i = (x_1^i,..., x_K^i)$, and $x = (x^i,..., x^N)$. Let p_k denote players' common prior k-type probability, and $\sum_{k=1}^{K} p_k = 1$ and $p = (p_1,..., p_K)$. Let ε_k denote the k-type error rate and $\varepsilon = (\varepsilon_1,..., \varepsilon_K)$. Given that a game has one type-k decision and c-1 non-type-k decisions, the probability of observing a particular sample with x_k^i type-k decisions when player i is type k can be written as:

$$L_k^i(\varepsilon_k \mid x_k^i) = \prod_{c=2,3,4} \left[1 - \frac{(1-c)}{c} \varepsilon_k\right]^{x_k^{ic}} \left[\frac{\varepsilon_k}{c}\right]^{T^c - x_k^{ic}} \tag{1}$$

Weighting the right-hand side by p_k, summing over k, taking logarithms, and summing over i yields the log-likelihood function for the entire sample:

$$\ln L(p, \varepsilon \mid x) = \sum_{i=1}^{n} \ln \sum_{k=1}^{K} p_k L_k^i(\varepsilon_k \mid x_k^i) \tag{2}$$

Table 10 about here

In Table 10 we provide an estimation of equation (2). We interpret the estimated probability p_k as the probability to find a player of type k in the population under observation. The bottom line of Table 10 reveals an estimated share of 41% of subjects to be a strategic type. Looking at the probability for single types, we note that the non-strategic type *optimistic* is the modal type with a probability of 40%. Three strategic types are significant and have an estimated probability of roughly 10% each. These are *L2* (best replying to *optimistic/naïve* types), *D1* (deleting dominated strategies once and then best replying to a uniform distribution of the remaining strategies), and *sophisticated* (playing best reply to the actually observed frequencies of different strategies).

To measure the effects of gender, age and other individual characteristics on the probability to belong to a given type we use the following procedure. Based on the estimation of (2), we use the estimated parameters $\hat{\varepsilon}_k$ and $\hat{p}_k$ to compute the probability by which each subject is assigned to a specific type, conditional on the observed pattern of choices.[23]

Table 11 about here

Table 11 presents Tobit regressions in which we regress the probability of subject *i* being classified into each of the eight different types on age (years), gender (1 = male), knowledge to play chess, and a subject's grades in math and German language. Including a dummy variable for playing chess was motivated by chess being a highly strategic game where players immediately notice that their success depends not only on own choices, but also on the opponent's choices. While the first eight regressions use as the dependent variable a subject's probability to belong to one of the eight types considered here, the ninth regression considers a subject's probability to be classified as a strategic decision making type as the dependent variable.

We see that age has an impact on the *altruistic* and *D1*-type. Older subjects are (weakly significantly) more likely to be *altruistic*/*efficiency-loving*, and more likely to apply one round of eliminating dominated strategies (*D1*-type). There is also a gender effect on these two types, such that boys are more likely of the *altruistic*/*efficiency-loving* type, while girls are more likely to be a *D1*-type. This holds true even when controlling for the other independent variables. Subjects with better math grade – note that lower grades mean better skills in the Austrian system – are more frequently classified as a *D1*-type. The relatively few *equilibrium*-types are largely influenced by good math grades and by playing chess in one's sparetime. Overall, the math grade has also an influence on the general likelihood to be a *strategic* type. However, age or gender has no effect on being a *strategic* type. This indicates that already 10-year olds are equally likely to play these normal-form games strategically as 17-year olds.

[23] For each subject and type, we compute probabilities (1) i.e. the probabilities to observe a given pattern of choices conditional on a type; we denote them by $P(x_i|k=h)$, where $h \in \{1, \ldots, 8\}$ and, with abuse of notation, x_i denotes the choices of individual *i*. Using Bayes Rule, we compute the probability that an individual *i* is a type-*k*, given the observed choices, i.e., $P_i(k=h|x_i)$ where $h \in \{1, \ldots, 8\}$. For example, the probability that individual *i* belongs to the *Altruistic* type (k=1), given the observed choices x_i, is given by the following equation: $P_i(k_i = 1 | x_i) = \dfrac{P(x_i | k=1)\hat{p}_1}{P(x_i | k=1)\hat{p}_1 + P(x_i | k=2)\hat{p}_2 + \ldots + P(x_i | k=8)\hat{p}_8}$.

Only for a specific strategic type, the *D1*-type, we have found a (weak, though) influence of age.

We can summarize the main results in this subsection as follows:

Result 4: The likelihood of subjects to be of any of five different strategic types (equilibrium, sophisticated, D1, D2, L2) is about 40%. The modal type, however, is a non-strategic optimistic type. Age has a positive effect on the probability to be an altruistic/efficiency-loving and a D1-type. The performance in mathematics is correlated with the probability to be one of the strategic types. Age has no impact on the latter probability, though.

4. Conclusion

In this paper we have studied strategic sophistication of 191 adolescents, aged 10 to 17 years, in 18 different normal-form games taken from Costa-Gomes et al. (2001). Overall, we have found that about 40% of subjects can be classified as strategic, thus taking into account their opponent's incentives and strategies when making decisions. Interestingly, we have found no influence of age on the likelihood to be strategic. This result suggests that at the age of 10 years strategic sophistication has already reached a level that – in the aggregate – does not change in the later teenage years. In fact, many of the stylized facts found in our experiment with teenagers are very similar to what is known from experiments with university students in their early 20ies. The relative frequency of playing Nash in the 18 different games is approximately 45% in our subject pool, which is well in the range of 40% to 50% of Nash-play reported in other studies (e.g., Costa-Gomes et al., 2001; Costa-Gomes and Weizsäcker, 2008; Fehr et al., 2012; Sutter et al., 2010a). The share of consistent decisions – as best response to one's own beliefs – is around 60% in our sample, while it is around 55% both in Costa-Gomes and Weizsäcker (2008) and Sutter et al. (2010a) who have run their experiments with university students. Hence, our first main finding is that teenagers and young adults in their early 20ies play normal form games in a very similar manner. In fact, we have only found a few noteworthy effects of age, in particular on the likelihood to be *altruistic/efficiency-loving* and a *D1*-type. Both get (weakly significantly) more likely with age. Analytic skills, captured in subjects' math grades, have a positive influence on being a strategic type in general, and a *D1*- or *equilibrium*-type in particular. Hence, experimental behavior in normal-form games is related to math skills. While the previous literature on strategic sophistication has not put much emphasis on gender effects, we have found a few results. Girls are more likely to be a *D1*-type, while boys are more likely to be *altruistic/efficiency-loving*.[24] In the aggregate, however, we have found no gender differences in the likelihood to be strategic.

While our paper contributes to the literature on strategic sophistication by showing that adolescents are able to play complex games in a way that is very similar to the behavior of adults (university students) and that age has no marked impact in strategic behavior, another contribution to this literature refers to the analysis of consistent decision making and the ability to predict other's real decision making by stating correct first- and second order beliefs. Our corresponding analyses include both game characteristics (such as the existence of dominant strategies or the number of available strategies) and players' individual characteristics (such as grades or the existence of siblings). Our results (in section 3.2) have shown that consistent choices (best replies to own first order beliefs) are highly dependent on the existence of dominant strategies, while for individual characteristics significant influences cannot be found. Nevertheless students with better grades in math have a significant higher probability to state consistent first order beliefs ("opponents expected consistency" – best reply to own second order beliefs). With regard to correct first- and second order beliefs our analysis has shown that the probability of a correct prediction is highly influenced by a game's complexity (defined by the existence of dominant strategies and the number of available strategies). Interestingly the ability to play chess turns out to be a disadvantage in correctly anticipating others' decisions. At the same time adolescents with siblings were doing significantly better in prediction other players' first order beliefs (by stating a "correct second order belief"). We cannot find a constant trend in age groups - neither for consistency of decisions nor for correctness of beliefs.

Given our results on the stability of behavior in our sample of 10- to 17-year olds, one straightforward extension of our study would be studying also subjects who are younger than 10 years of age in order to determine whether and when noticeable changes in the ability to act and think strategically develop. Our experimental design is most likely not the optimal choice for younger children below the age of 10 years, because the games used in our study and the decisions on first- and second-order beliefs might easily overburden younger children. While we have chosen our design due to its suitability for studying different types of strategic

[24] The latter finding resonates in simple distribution experiments where boys are more often found to care for efficiency than girls. See Sutter et al. (2010b).

and non-strategic behavior and because a lot of evidence from college or university students in their early 20ies is available for comparison, we regard it as an interesting avenue for future research to design simpler games that could provide insights into how strategic sophistication, and the interaction of choices and beliefs, develops in the first ten years of human life.

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Tables and Figures

Table 1: Choices and beliefs of adolescents (relative frequencies in %)

	All games	*D-games*	*ND-games*
		CHOICES	
Nash **5th grade**	47.90	64.67	26.94
Nash **7th grade**	45.62	62.12	25.00
Nash **9th grade**	45.83	63.08	24.28
Nash **11th grade**	41.53	59.05	19.64
Pareto **5th grade**	43.58	31.56	58.61
Pareto **7th grade**	46.80	35.38	61.06
Pareto **9th grade**	46.05	33.85	61.30
Pareto **11th grade**	50.40	38.33	65.48
Other **5th grade**	8.52	3.78	14.44
Other **7th grade**	7.59	2.50	13.94
Other **9th grade**	8.12	3.08	14.42
Other **11th grade**	8.07	2.62	14.88
		FIRST-ORDER BELIEFS	
Nash **5th grade**	34.81	51.33	14.17
Nash **7th grade**	33.01	49.23	12.74
Nash **9th grade**	34.83	51.92	13.46
Nash **11th grade**	34.26	51.67	12.50
Pareto **5th grade**	57.16	46.44	70.56
Pareto **7th grade**	59.94	48.46	74.28
Pareto **9th grade**	57.05	45.19	71.88
Pareto **11th grade**	57.14	44.76	72.62
Other **5th grade**	8.03	2.22	15.28
Other **7th grade**	7.05	2.31	12.98
Other **9th grade**	8.12	2.88	14.66
Other **11th grade**	8.60	3.57	14.88
		SECOND-ORDER BELIEFS	
Nash **5th grade**	37.90	51.33	21.11*
Nash **7th grade**	32.59	48.27	12.98
Nash **9th grade**	34.19	49.62	14.90
Nash **11th grade**	34.26	50.48	13.99
Pareto **5th grade**	55.31	46.00	66.94
Pareto **7th grade**	59.30	49.04	72.12
Pareto **9th grade**	56.52	47.50	67.79
Pareto **11th grade**	57.01	46.67	69.94
Other **5th grade**	6.79	2.67	11.94*
Other **7th grade**	8.12	2.69	14.90
Other **9th grade**	9.30	2.88	17.31
Other **11th grade**	8.73	2.86	16.07

** (*) significant difference at $p < 0.05$ ($p < 0.1$) across all age groups for a particular set of games and a given strategy according to a two-sided Kruskal-Wallis test.

Table 2: Complexity of the game, choices and beliefs (relative frequencies in %)

Complexity (game type)[a]	***1R (D)***	***2R (D)***	***2R (ND)***	***3R (ND)***	***∞R (ND)***
			CHOICES		
Nash **5th grade**	89.78	39.56	38.89	8.88	30.00
Nash **7th grade**	86.15	38.08	35.58	7.69	28.37
Nash **9th grade**	83.46	42.69	36.54	7.69	26.44
Nash **11th grade**	81.90	36.19	28.57	8.33	20.83
Pareto **5th grade**	6.22	56.89	61.11	42.22**	65.56
Pareto **7th grade**	11.15	59.62	64.42	45.19	67.31
Pareto **9th grade**	15.00	52.69	63.46	55.77	62.98
Pareto **11th grade**	16.19	60.48	71.43	47.62	71.43
Other **5th grade**	4.00	3.56	0.00	48.89**	4.44
Other **7th grade**	2.69	2.31	0.00	47.12	4.33
Other **9th grade**	1.54	4.62	0.00	36.54	10.58
Other **11th grade**	1.90	3.33	0.00	44.05	7.74
			FIRST-ORDER BELIEFS		
Nash **5th grade**	87.11	15.56	14.44	13.33	14.44
Nash **7th grade**	87.69	10.77	15.38	10.58	12.50
Nash **9th grade**	86.54	17.31	15.38	7.69	15.38
Nash **11th grade**	86.67	16.67	11.90	5.95	16.07
Pareto **5th grade**	12.00	80.89	85.56	42.22*	77.22
Pareto **7th grade**	10.00	86.92	84.62	46.15	83.17
Pareto **9th grade**	11.54	78.85	84.62	55.77	73.56
Pareto **11th grade**	9.52	80.00	88.10	47.62	77.38
Other **5th grade**	0.89	3.56	0.00	44.44	8.33*
Other **7th grade**	2.31	2.31	0.00	43.27	4.33
Other **9th grade**	1.92	3.85	0.00	36.54	11.06
Other **11th grade**	3.81	3.33	0.00	46.43	6.55
			SECOND-ORDER BELIEFS		
Nash **5th grade**	77.78	24.89*	20.00	22.22**	21.11
Nash **7th grade**	82.69	13.85	13.46	8.65	14.91
Nash **9th grade**	77.69	21.54	11.54	8.65	19.71
Nash **11th grade**	85.71	15.24	9.52	8.33	19.05
Pareto **5th grade**	18.67	73.33	80.00	44.44	71.67
Pareto **7th grade**	15.00	83.08	86.54	46.15	77.88
Pareto **9th grade**	20.38	74.62	88.46	50.00	66.35
Pareto **11th grade**	11.43	81.90	90.48	45.24	72.02
Other **5th grade**	3.56	1.78	0.00	33.33*	7.22
Other **7th grade**	2.31	3.08	0.00	45.19	7.21
Other **9th grade**	1.92	3.85	0.00	41.35	13.94
Other **11th grade**	2.86	2.86	0.00	46.43	8.93

** (*) significant difference at $p < 0.05$ ($p < 0.1$) across all age groups for a particular set of games and a given strategy according to a two-sided Kruskal-Wallis test.

[a] The columns separate behavior according to (i) the different number of rounds (***R***) of iterated pure-strategy dominance a player needs to identify the own equilibrium choice, and (ii) the presence (***D***) or absence (***ND***) of a dominant strategy in the game.

Table 3: Percentages of decisions that comply with equilibrium, contingent on game-type

	Complexity (game # for rows // game # for columns)	**5th grade**	**7th grade**	**9th grade**	**11th grade**
Choice	*1 round of dominance to identify own equilibrium choice*				
	2x2 with dominant decision (#3, #13 // #1, #12)	91.11	85.58	82.69	84.52
	2x3 with dominant decision (#16 // #11)	93.33	90.38	80.77	83.33
	3x2 with dominant decision (#9 // #7)	82.22	86.54	88.46	73.81
	4x2 with dominant decision (#17 // #18)	91.11	82.69	82.69	83.33
	2 rounds of dominance				
	2x2, partner has dominant decision (#1, #12 // #3, #13)	41.11	45.19	45.19	34.52
	2x3, partner has dominant decision (#7 // #9)	40.00	32.69	40.38	33.33
	3x2, partner has dominant decision (#11 // #16)	31.11	34.62	36.54	35.71
	2x4, partner has dominant decision (#18 // #17)	44.44	32.69	46.15	42.86
	2x3 with 2 rounds of dominance (#2, #14 // #6, # 15)	38.89	35.58	36.54	28.57
	3 rounds of dominance				
	3x2 with 3 rounds of dominance (#6, #15 // #2, #14)	8.88	7.69	7.69	8.33
	No dominance				
	2x3, unique equilibrium, no dominance (#8, #10 // # 4, #5)	43.33	37.50	35.58	30.95
	3x2, unique equilibrium, no dominance (#4, #5 // #8, #10)	16.67	19.23	17.31	10.71
First order beliefs	*1 round of dominance to identify own equilibrium choice*				
	2x2 with dominant decision (#3, #13 // #1, #12)	87.78	86.54	89.42	89.29
	2x3 with dominant decision (#16 // #11)	86.67	98.08	84.62	90.48
	3x2 with dominant decision (#9 // #7)	82.22	88.46	88.46	80.95
	4x2 with dominant decision (#17 // #18)	91.11	78.85	80.77	83.33
	2 rounds of dominance				
	2x2, partner has dominant decision (#1, #12 // #3, #13)	15.56	14.42	19.23	16.67
	2x3, partner has dominant decision (#7 // #9)	26.67	11.54	26.92	16.67
	3x2, partner has dominant decision (#11 // #16)	0.00	7.69	5.77	11.90
	2x4, partner has dominant decision (#18 // #17)	20.00	5.77	15.38	21.43
	2x3 with 2 rounds of dominance (#2, #14 // #6, # 15)	14.44	15.38	15.38	11.90
	3 rounds of dominance				
	3x2 with 3 rounds of dominance (#6, #15 // #2, #14)	13.33	10.58	7.69	5.95
	No dominance				
	2x3, unique equilibrium, no dominance (#8, #10 // # 4, #5)	16.67	19.23	22.12	21.43
	3x2, unique equilibrium, no dominance (#4, #5 // #8, #10)	12.22	5.77	8.65	10.71
Second order beliefs	*1 round of dominance to identify own equilibrium choice*				
	2x2 with dominant decision (#3, #13 // #1, #12)	80.44	82.69	80.77	91.67
	2x3 with dominant decision (#16 // #11)	71.11	86.54	69.23	76.19
	3x2 with dominant decision (#9 // #7)	73.33	82.69	88.46	80.95
	4x2 with dominant decision (#17 // #18)	75.56	78.85	69.23	88.10
	2 rounds of dominance				
	2x2, partner has dominant decision (#1, #12 // #3, #13)	30.00*	16.35*	27.88*	16.67*
	2x3, partner has dominant decision (#7 // #9)	28.89	13.46	17.31	23.81
	3x2, partner has dominant decision (#11 // #16)	15.56	13.46	15.38	11.90
	2x4, partner has dominant decision (#18 // #17)	20.00	9.62	19.23	7.14
	2x3 with 2 rounds of dominance (#2, #14 // #6, # 15)	20.00	13.46	11.54	9.52
	3 rounds of dominance				
	3x2 with 3 rounds of dominance (#6, #15 // #2, #14)	22.22**	8.65**	8.65**	8.33**
	No dominance				
	2x3, unique equilibrium, no dominance (#8, #10 // # 4, #5)	22.22	19.23	25.96	29.76
	3x2, unique equilibrium, no dominance (#4, #5 // #8, #10)	20.00	10.58	13.46	8.33

** (*) significant difference at $p < 0.05$ ($p < 0.1$) across all age groups for equilibrium play in a particular set of games according to a two-sided Kruskal-Wallis test.

Table 4: Consistency of decisions (relative frequency of best reply)

		All games	*D-games*	*ND-games*
Own consistency	**5th grade**	64.44	67.78	60.28
Choice is best reply to first-	**7th grade**	61.47	64.32	57.93
order belief	**9th grade**	64.42	68.27	59.62
	11th grade	60.85	64.05	56.85
Opponent's expected	**5th grade**	50.99	55.78	45.00
consistency	**7th grade**	51.99	53.42	50.24
First-order belief is best	**9th grade**	55.98	60.00	50.96
reply to second-order belief	**11th grade**	51.59	55.24	47.02

** (*) significant difference at $p < 0.05$ ($p < 0.1$) across all age groups for a particular set of games and a given strategy according to a two-sided Kruskal-Wallis test.

Table 5: Relative frequency of consistency-types Nash-CON and Max-CON

		All games	*D-games*	*ND-games*
	Nash-CON **5th grade**	15.56	23.78	5.28
	Nash-CON **7th grade**	14.55	21.60	5.77
	Nash-CON **9th grade**	18.38	27.69	6.73
Player's own consistency	Nash-CON **11th grade**	15.48	24.76	3.87
	Max-CON **5th grade**	40.99	42.00	39.72
	Max-CON **7th grade**	39.77	41.37	37.74
	Max-CON **9th grade**	38.03	37.69	38.46
	Max-CON **11th grade**	37.70	36.43	39.29
	Nash-CON **5th grade**	10.13**	14.67**	4.44
	Nash-CON **7th grade**	6.22	9.32	2.40
	Nash-CON **9th grade**	11.22	16.92	4.09
Expected consistency of opponent	Nash-CON **11th grade**	8.99	12.86	4.17
	Max-CON **5th grade**	37.90	39.56	35.83
	Max-CON **7th grade**	42.34	42.54	42.07
	Max-CON **9th grade**	40.92	40.58	41.35
	Max-CON **11th grade**	39.29	40.71	37.50

** (*) significant difference at $p < 0.05$ ($p < 0.1$) across all age groups for a particular set of games and a given strategy according to a two-sided Kruskal-Wallis test.

Table 6: Determinants of a correct first order belief

Variable	*Coefficient*	*Std. error*	*p-value*
dominant strategy	-0.245	0.055	0.000
opponent dominant strategy	0.367	0.061	0.000
dummy for **7th grade**	0.019	0.115	0.871
dummy for **9th grade**	-0.108	0.118	0.362
dummy for **11th grade**	0.015	0.116	0.895
# of other’s strategies	-0.117	0.039	0.003
ability to play chess	-0.183	0.081	0.023
math grade	0.016	0.046	0.724
german grade	-0.036	0.052	0.489
existence of siblings	-0.006	0.036	0.857
Constant	0.779	0.147	0.000

N = 3.239; standard errors clustered for the 180 decision makers (45 in 5th grade, 41 in 7th grade, 52 in 9th grade, 42 in 11th grade).

Marginal effects of independent variables

	Marginal effect	*Std. error*	*p-value*
dominant strategy	-0.094	0.021	0.000
opponent dominant strategy	0.134	0.021	0.000
dummy for **7th grade**	0.007	0.043	0.871
dummy for **9th grade**	-0.041	0.045	0.362
dummy for **11th grade**	0.006	0.044	0.895
# of other’s strategies	-0.044	0.015	0.003
ability to play chess	-0.068	0.030	0.023
math grade	0.006	0.017	0.724
german grade	-0.014	0.020	0.489
existence of siblings	-0.002	0.014	0.857

N = 3.239; standard errors clustered for the 180 decision makers (45 in 5th grade, 41 in 7th grade, 52 in 9th grade, 42 in 11th grade).

Table 7: Determinants of a correct second order belief

Variable	*Coefficient*	*Std. error*	*p-value*
dominant strategy	0.294	0.060	0.000
opponent dominant strategy	-0.024	0.061	0.698
dummy for **7^{th} grade**	0.250	0.126	0.048
dummy for **9^{th} grade**	0.111	0.126	0.376
dummy for **11^{th} grade**	0.314	0.124	0.011
# of strategies	-0.231	0.036	0.000
ability to play chess	-0.146	0.089	0.098
math grade	0.047	0.049	0.340
german grade	-0.077	0.049	0.118
existence of siblings	0.078	0.040	0.051
Constant	0.843	0.150	0.000

N = 3.239; standard errors clustered for the 180 decision makers (45 in 5^{th} grade, 41 in 7^{th} grade, 52 in 9^{th} grade, 42 in 11^{th} grade).

Marginal effects of independent variables

	Marginal effect	*Std. error*	*p-value*
dominant strategy	0.102	0.020	0.000
opponent dominant strategy	-0.009	0.022	0.698
dummy for **7^{th} grade**	0.087	0.042	0.048
dummy for **9^{th} grade**	0.039	0.044	0.376
dummy for **11^{th} grade**	0.108	0.040	0.011
# of strategies	-0.083	0.013	0.000
ability to play chess	-0.052	0.031	0.098
math grade	0.017	0.017	0.340
german grade	-0.028	0.018	0.118
existence of siblings	0.028	0.014	0.051

N = 3.239; standard errors clustered for the 180 decision makers (45 in 5^{th} grade, 41 in 7^{th} grade, 52 in 9^{th} grade, 42 in 11^{th} grade).

Table 8: Determinants of a player's "own consistency"

Variable	*Coefficient*	*Std. error*	*p-value*
dominant strategy	0.864	0.074	0.000
opponent dominant strategy	-0.301	0.055	0.000
dummy for **7th grade**	0.096	0.147	0.513
dummy for **9th grade**	0.132	0.151	0.381
dummy for **11th grade**	-0.049	0.148	0.740
# of game results	0.012	0.017	0.481
ability to play chess	-0.140	0.099	0.159
math grade	-0.090	0.056	0.107
german grade	0.038	0.056	0.498
existence of siblings	0.018	0.043	0.671
Constant	0.324	0.166	0.051

N = 3.239; standard errors clustered for the 180 decision makers (45 in 5th grade, 41 in 7th grade, 52 in 9th grade, 42 in 11th grade).

Marginal effects of independent variables

	Marginal effect	*Std. error*	*p-value*
dominant strategy	0.284	0.021	0.000
opponent dominant strategy	-0.113	0.021	0.000
dummy for **7th grade**	0.035	0.053	0.513
dummy for **9th grade**	0.048	0.054	0.381
dummy for **11th grade**	-0.018	0.055	0.740
# of game results	0.004	0.006	0.481
ability to play chess	-0.051	0.036	0.159
math grade	-0.033	0.020	0.107
german grade	0.014	0.021	0.498
existence of siblings	0.007	0.016	0.671

N = 3.239; standard errors clustered for the 180 decision makers (45 in 5th grade, 41 in 7th grade, 52 in 9th grade, 42 in 11th grade).

Table 9: Determinants of a player's "opponent's expected consistency"

Variable	*Coefficient*	*Std. error*	*p-value*
dominant strategy	-0.636	0.067	0.000
opponent dominant strategy	1.202	0.085	0.000
dummy for **7th grade**	0.157	0.071	0.026
dummy for **9th grade**	0.304	0.099	0.002
dummy for **11th grade**	0.109	0.091	0.232
# of game results	-0.019	0.020	0.354
ability to play chess	-0.082	0.055	0.133
math grade	-0.092	0.041	0.026
german grade	0.025	0.042	0.562
existence of siblings	0.032	0.026	0.223
Constant	0.101	0.136	0.455

N = 3.239; standard errors clustered for the 180 decision makers (45 in 5th grade, 41 in 7th grade, 52 in 9th grade, 42 in 11th grade).

Marginal effects of independent variables

	Marginal effect	*Std. error*	*p-value*
dominant strategy	-0.250	0.025	0.000
opponent dominant strategy	0.423	0.023	0.000
dummy for **7th grade**	0.062	0.028	0.026
dummy for **9th grade**	0.119	0.038	0.002
dummy for **11th grade**	0.043	0.036	0.232
# of game results	-0.007	0.008	0.354
ability to play chess	-0.032	0.022	0.133
math grade	-0.036	0.016	0.026
german grade	0.010	0.017	0.562
existence of siblings	0.013	0.010	0.223

N = 3.239; standard errors clustered for the 180 decision makers (45 in 5th grade, 41 in 7th grade, 52 in 9th grade, 42 in 11th grade).

Table 10: Estimated probability p_k of types – Own choices

Age group	
Altruistic / Efficiency-loving	0.039***
Pessimistic	0.146***
Optimistic	0.404***
L2	0.138***
D1	0.107***
D2	0.040
Equilibrium	0.026
Sophisticated	0.100**
Sum Strategic types	0.410***

*** (**) [*] significant at 1% (5%) [10%] level

Table 11: Tobit regressions

		Coefficient	*Std. Error*	*p-value*
Alturistic	*gender (1=male)*	0.051	0.029	0.081
	age (in years)	0.014	0.007	0.069
	chess	0.041	0.031	0.185
	mathgrade	-0.004	0.017	0.837
	germangrade	0.002	0.020	0.931
	constant	-0.183	0.091	0.045
Pessimistic	*gender (1=male)*	-0.032	0.043	0.458
	age (in years)	-0.004	0.011	0.688
	chess	0.027	0.045	0.559
	mathgrade	0.014	0.025	0.569
	germangrade	0.001	0.029	0.985
	constant	0.162	0.133	0.224
Optimistic	*gender (1=male)*	-0.004	0.072	0.952
	age (in years)	-0.021	0.018	0.254
	chess	-0.001	0.077	0.988
	mathgrade	0.067	0.043	0.117
	germangrade	-0.036	0.050	0.473
	constant	0.603	0.225	0.008
L2-type	*gender (1=male)*	0.011	0.050	0.823
	age (in years)	-0.007	0.013	0.569
	chess	-0.064	0.053	0.225
	mathgrade	0.005	0.029	0.864
	germangrade	-0.048	0.034	0.164
	constant	0.370	0.154	0.017
D1-type	*gender (1=male)*	-0.070	0.035	0.050
	age (in years)	0.016	0.009	0.071
	chess	-0.030	0.038	0.433
	mathgrade	-0.049	0.021	0.019
	germangrade	0.048	0.024	0.048
	constant	-0.038	0.110	0.731
D2-type	*gender (1=male)*	0.010	0.013	0.470
	age (in years)	0.001	0.003	0.808
	chess	-0.008	0.014	0.562
	mathgrade	0.005	0.008	0.506
	germangrade	-0.005	0.009	0.539
	constant	0.017	0.042	0.683
Equilibrium	*gender (1=male)*	0.022	0.021	0.301
	age (in years)	0.002	0.005	0.755
	chess	0.041	0.023	0.075
	mathgrade	-0.025	0.013	0.049
	germangrade	0.014	0.015	0.332
	constant	-0.006	0.066	0.923
Sophisticated	*gender (1=male)*	0.012	0.031	0.704
	age (in years)	0.000	0.008	0.988
	chess	-0.005	0.032	0.866
	mathgrade	-0.014	0.018	0.437
	germangrade	0.024	0.021	0.255
	constant	0.075	0.095	0.433
Sum	*gender (1=male)*	-0.015	0.070	0.828
Strategic types	*age (in years)*	0.012	0.018	0.511
	chess	-0.067	0.075	0.373
	mathgrade	-0.078	0.042	0.062
	germangrade	0.033	0.048	0.490
	constant	0.418	0.219	0.058

Figure 1. The 18 normal-form games

game # 3 (*D*) **[1R, 2R]**

	1	2
1	72, 93	31, 46
2	84, 52	55, 79

game # 13 (*D*) **[1R, 2R]**

	1	2
1	94, 23	38, 57
2	45, 89	14, 18

game # 1 (*D*) **[2R, 1R]**

	1	2
1	75, 51	42, 27
2	48, 80	89, 68

game # 12 (*D*) **[2R, 1R]**

	1	2
1	21, 92	87, 43
2	55, 36	16, 12

game # 7 (*D*) **[2R, 1R]**

	1	2	3
1	59, 58	46, 83	85, 61
2	38, 29	70, 52	37, 23

game # 11 (*D*) **[2R, 1R]**

	1	2
1	31, 32	68, 46
2	72, 43	47, 61
3	91, 65	43, 84

game # 9 (*D*) **[1R, 2R]**

	1	2
1	28, 37	57, 58
2	22, 36	60, 84
3	51, 69	82, 45

game # 16 (*D*) **[1R, 2R]**

	1	2	3
1	42, 64	57, 43	80, 39
2	28, 27	39, 68	61, 87

game # 6 (*ND*) **[3R, 2R]**

	1	2
1	53, 86	24, 19
2	79, 57	42, 73
3	28, 23	71, 50

game # 15 (*ND*) **[3R, 2R]**

	1	2
1	76, 93	25, 12
2	43, 40	74, 62
3	94, 16	59, 37

game # 14 (*ND*) **[2R, 3R)**

	1	2	3
1	21, 26	52, 73	75, 44
2	88, 55	25, 30	59, 81

game # 2 (*ND*) **[2R, 3R]**

	1	2	3
1	42, 45	95, 78	18, 96
2	64, 76	14, 27	39, 61

game # 8 (*ND*) **[∞R, ∞R]**

	1	2	3
1	87, 32	18, 37	63, 76
2	65, 89	96, 63	24, 30

game # 10 (*ND*) **[∞R, ∞R]**

	1	2	3
1	67, 91	95, 64	31, 35
2	89, 49	23, 53	56, 78

game # 5 (*ND*) **[∞R, ∞R]**

	1	2
1	72, 59	26, 20
2	33, 14	59, 92
3	28, 83	85, 61

game # 4 (*ND*) **[∞R, ∞R]**

	1	2
1	46, 16	57, 88
2	71, 49	28, 24
3	42, 82	84, 60

game # 17 (*D*) **[1R, 2R]**

	1	2
1	22, 14	57, 55
2	30, 42	28, 37
3	15, 60	61, 88
4	45, 66	82, 31

game# 18 (*D*) **[2R, 1R]**

	1	2	3	4
1	56, 58	38, 29	89, 62	32, 86
2	15, 23	43, 31	61, 16	67, 46

Supplementary material

A. Experimental instructions

Instructions were read aloud at the beginning of each session. Before the experiment started, all participants had to answer control questions in order to make sure that they understood the instructions. Instructions primarily served as a basic guideline for a very detailed explanation of the game. As we wanted to be sure that our participants understood the rules of the game we took a lot of effort to explain them the instructions in a very detailed way and if necessary even personally. Originally all instructions were in German. In the following we present an English translation of the instructions and control questions used.
Instructions for 5th and 7th graders differ from instructions for 9th and 11th graders with respect to payoffs. In the following we present instructions for 5th and 7th graders as a baseline and indicate payoffs which were used for 9th and 11th graders in brackets and underlined letters.

Welcome! In this game it is very important that you do not communicate with any of your class mates for the whole duration of the game. Students who break this rule will be excluded from the game. You will earn some money by playing this game which will be paid to you at the end of the game. The amount of money you earn strongly depends on your decisions during the game. Thus it is very important that you understand the rules of the game. Please read the instructions carefully. As soon as you have any questions, please raise your hand and an instructor of the game will come to you in order to answer your questions.

Today we will play a game consisting of 18 sub-games. Each sub-game is printed on a separate sheet of paper and consists of three decisions each player needs to make. The rules for those three decisions will be explained to you soon. Each player gets 18 sheets on which he needs to make his decisions.
You will play in groups of two students. Each student of this room will be matched with a student from another room. In this other room students from your parallel-class play the same game right now. The student with the number one in this room will be matched with student number one in the other room, student number two in this room will be matched with student number two in the other room etc. Same as you did, students in the other room have drawn numbers randomly. We take care that each student in this room is paired with a student in the other room. In the following we will call the student who is matched with you as “the other player” or “your interaction partner”.

We would like to explain the rules of the game based on the following examples:

Example for decision 1:

Which row do you want to choose?

		§§	%%	@@	μμ
O	§	65	47		
O	%	23	93		
	@				
	μ				

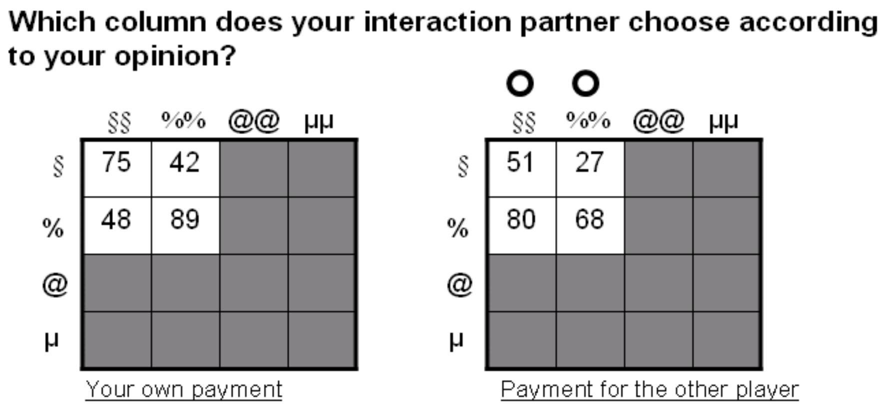
Your own payments

	§§	%%	@@	μμ
§	57	32		
%	85	71		
@				
μ				

Payments for the other player

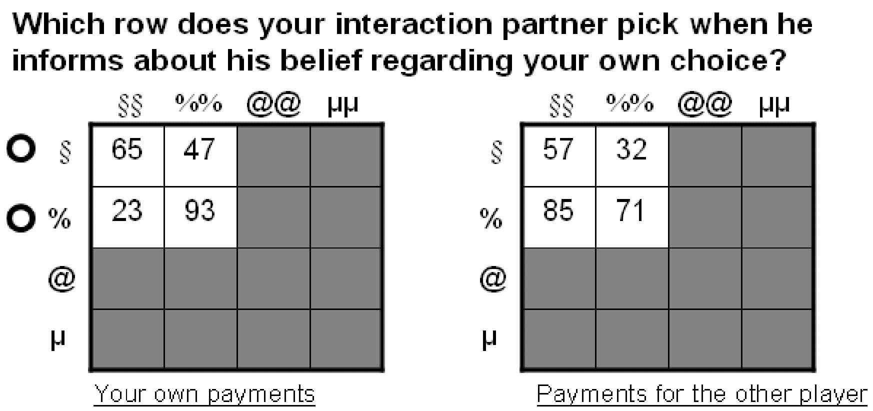
In the upper part of each sheet you need to make a decision. In this example you need to choose one of two options. The first option (first row) is indicated with the sign § and the second option (second row) is indicated with the sign %. Your interaction partner also has two options in this example. His options are columns which are always indicated with two signs of the same kind. The first option of the other player is indicated with §§ and the second option is indicated with %%.
Based on the row that you have chosen and the column that your interaction partner has chosen the potential payment for both players is determined. This is done as follows: The table on the left hand side contains four possible payments dedicated to you and measured in game points. The table on the right hand side contains four possible payments dedicated for the opponent player – again measured in game points. The cell that is relevant for payment is dependent on your own decision and on the decision of your interaction partner.
Let’s assume you choose the row indicated with the sign § and your interaction partner chooses the column indicated with the signs §§. In this particular case you would get 65 points and your interaction partner would get 57 points. Let’s assume another case in which you choose the row indicated with the sign % and the other player chooses the column indicated with the signs §§. In this case you would get 23 points and your interaction partner would get 85 points.
You can make your choice by marking the circle next to the sign you want to pick with a cross.

Example for decision 2:



In the middle of each sheet we ask you for your opinion about your interaction partner's choice.
For example if you would belief that your interaction partner chooses the column indicated by the signs §§ you need to mark the circle above those signs with a cross. If you think that your interaction partner chooses the column marked with the signs %% you need to mark the circle above the signs %% with a cross. Please note that correct beliefs can result in considerable higher payments.

Example for decision 3:



In the lower part of each sheet we ask you for your opinion about your interaction partner's belief regarding your own choice.
For example if you belief that your interaction partner expects you to choose the row indicated with the sign § you need to mark the circle next to the sign § with a cross. If you think that your interaction partner expects you to choose the row indicated with the sign % you need to mark the circle next to the sign % with a cross. Please note that correct beliefs can result in considerable higher payments.

In the example illustrated above each player has two options from which he can choose. In general there are also games in which one of the two players has not only two, but three or four options from which he can choose.

Calculation of payments:
At the end of the whole experiment we will randomly select a sheet which is relevant for payment. We have a deck of cards showing the numbers 1 to 18 from which you or the other player will be allowed to draw one card. The number shown on this card determines the sheet which is relevant for payment.

In addition you will select one decision which will be basis for your payment.
Your decisions are:
- which row is your own choice
- which column chooses your interaction partner according to your opinion
- which row does your interaction partner pick when he informs about his belief regarding your own choice

The selection of the decision that is going to be relevant for payment will be random. You or your interaction partner will draw a card from a deck of three cards showing the numbers 1-3.

Payment for decision 1:
In the case that the card showing the number 1 is drawn, you and your interaction partner get paid for the first decision. Each point will be converted into Euro according to the following exchange rate

1 point = 0.10 Euros (0.20 Euros)

Let's assume you have chosen § and your interaction partner has chosen %%. In the example illustrated before this would mean that you earn 4.7 Euros (9.4 Euros) (0.1 * 47 points) (0.2 * 47 points) while your interaction partner earns 3.2 Euros (6.4 Euros) (0.1 * 32 points) (0.2 * 32 points).

Payment for decision 2:
In the case that the card showing the number 2 is drawn, you and your interaction partner get paid for the second decision. In this case you will get 5 Euros (10 Euros) if your prediction of your interaction partner's choice was correct. If your prediction was incorrect you will get no payment in this case.

Payment for decision 3:
In the case that the card showing the number 3 is drawn, you and your interaction partner get paid for the third decision. In this case you get 5 Euros (10 Euros) if your prediction of your interaction partner's expectation (regarding your own choice) was correct. If your prediction was incorrect you will get no payment in this case.

In addition to the payments described in the former each participant of the game gets a fixed amount of 2 Euros (4 Euros) for attending the game.

Example 1

Which row do you want to choose?

		§§	%%	@@	μμ
⊗	§	77	39		
O	%	69	55		
	@				
	μ				

Your own payments

	§§	%%	@@	μμ
§	51	62		
%	35	44		
@				
μ				

Payments for the other player

Which column does your interaction partner choose according to your opinion?

	§§	%%	@@	μμ
§	77	39		
%	69	55		
@				
μ				

Your own payments

	O	⊗		
	§§	%%	@@	μμ
§	51	62		
%	35	44		
@				
μ				

Payments for the other player

Which row does your interaction partner pick when he informs about his belief regarding your own choice?

		§§	%%	@@	μμ
⊗	§	77	39		
O	%	69	55		
	@				
	μ				

Your own payments

	§§	%%	@@	μμ
§	51	62		
%	35	44		
@				
μ				

Payments for the other player

Participant ID: _________ **Class ID:** ______

Control-questions:

1) Assume you and your interaction partner get paid for decision 1.

a) what is your payment in points / Euro in the case your interaction partner has chosen §§?

__________ points ________ Euro

b) what is your interaction partners payment in points Euro, in the case he has chosen %%?

__________ points ________ Euro

c) what is your payment in points / Euro in the case your interaction partner has chosen %%?

__________ points ________ Euro

2) Assume you and your interaction partner get paid for decision 2.

a) what is your payment in the case your interaction partner has chosen §§ when he took decision 1?

__________ Euro

3) Assume you and your interaction partner get paid for decision 3.

a) what is your payment in the case your interaction partner has chosen § when he took decision 2?

__________ Euro

Example 2

Which row do you want to choose?

		§§	%%	@@	μμ
O	§	67	33		
O	%	30	28		
O	@	47	68		
⊗	μ	71	32		

Your own payments

	§§	%%	@@	μμ
§	55	34		
%	69	34		
@	37	53		
μ	75	60		

Payments for the other player

Which column does your interaction partner choose according to your opinion?

	§§	%%	@@	μμ
§	67	33		
%	30	28		
@	47	68		
μ	71	32		

Your own payments

	⊗	O		
	§§	%%	@@	μμ
§	55	34		
%	69	34		
@	37	53		
μ	75	60		

Payments for the other player

Which row does your interaction partner pick when he informs about his belief regarding your own choice?

		§§	%%	@@	μμ
O	§	67	33		
O	%	30	28		
O	@	47	68		
⊗	μ	71	32		

Your own payments

	§§	%%	@@	μμ
§	55	34		
%	69	34		
@	37	53		
μ	75	60		

Payments for the other player

Participant ID: _________ **Class ID:** ______

Control-questions:

1) Assume you and your interaction partner get paid for decision 1.

a) what is your payment in points / Euro in the case your interaction partner has chosen §§?

__________ points ________ Euro

b) what is your interaction partners payment in points / Euro, in the case he has chosen §§?

__________ points ________ Euro

c) what is your payment in points / Euro in the case your interaction partner has chosen %%?

__________ points ________ Euro

2) Assume you and your interaction partner get paid for decision 2.

a) what is your payment in the case your interaction partner has chosen §§ when he took decision 1?

__________ Euro

3) Assume you and your interaction partner get paid for decision 3.

a) what is your payment in the case your interaction partner has chosen @ when he took decision 2?

__________ Euro