Title
Information Acquisition in the Iterated Prisoner's Dilemma Game: An Eye-Tracking Study

Authors
Grinberg, Maurice
Hristova, Evgenia

Peer reviewed

Information Acquisition in the Iterated Prisoner's Dilemma Game:
An Eye-Tracking Study

Evgenia Hristova (ehristova@cogs.nbu.bg)
Central and Eastern European Center for Cognitive Science,
New Bulgarian University, 21, Montevideo street, Sofia 1618, Bulgaria

Maurice Grinberg (mgrinberg@nbu.bg)
Central and Eastern European Center for Cognitive Science,
New Bulgarian University, 21, Montevideo street, Sofia 1618, Bulgaria

Abstract

Eye-tracking recordings were used to explore the choice process in playing the iterated Prisoner's dilemma. This is a novel approach in studying the cognitive processes in game playing. The information acquisition patterns of two groups of subjects, identified on the basis of their playing behavior, were compared. The subjects from the first group paid more attention to the game payoffs and showed a strong dependence on their relative magnitudes. The subjects from the second group paid less attention to the payoff matrix but spent more time considering the opponent moves. These results show that the analysis of eye movement can give valuable information about the processes of decision making.

Keywords: eye-tracking; prisoner's dillema game; information aquisition.

Introduction

The iterated Prisoner's Dilemma (PD) game has been widely used as a model for exploring the determinants of cooperative behavior in social situations. The PD game has attracted much attention in the scientific literature and considerable numbers of papers have appeared (e.g. Rapoport & Chammah, 1965; Rapoport & Mowshowitz, 1966 and more recently Camerer & Ho, 2002; Erev & Roth, 2001; Macy & Flache, 2002).

However, no considerable efforts were invested in the careful study of the cognitive processes involved in playing the PD game. For instance, questions like what are the specific patterns of information acquisition about the game and how they are related to the behaviour observed (like the dependence of the moves on the so-called cooperation index, Rapoport & Chammah, 1965) remain open.

One of the strong assumptions in the formal game theory is that the players have complete knowledge about the game, the possible strategies and payoffs (Colman, 2003). The psychological game theory and behavioural game theory are expected to provide better predictions of experimental observations (Colman, 2003; Camerer, 2003). They are based on experimentally determined psychological regularities and seem to give more accurate explanations than traditional game theory.

The bounded rationality theoretical framework (see e.g. Simon, 1955), implies limitations on cognition and states that people devote limited efforts in making decisions. Computations are cognitively expensive and people usually try to avoid them. According to these theories, rationality should be replaced by a behavior compatible with limited access to information and limited computational capacity (Simon, 1955; Einhorn & Hogarth, 1981).

Playing PD games surely demands a considerable cognitive effort. To grasp the whole structure of the game, the player should pay attention not only to his payoffs but also to take into account the possible payoffs of the other player. What's more, the game outcome for the player depends not only on her moves but also on the moves of the opponent. Form the bounded rationality standpoint, we can hypothesize that, in the case of PD, subjects are also using only a limited portion of the available information and are not reasoning much ahead about their opponent's moves. Although suboptimal, with regard to the game theoretical reasoning, such a behavior requires less cognitive resources and seems much more plausible to take place in reality. This brief discussion shows how important the detailed investigation of the information processing is in order to understand the specific judgment and decision making processes that take place in game playing.

In the present paper, we study the typical patterns of information acquisition in PD games by recording eye movements. This is an attempt to reveal the actual cognitive processes involved in playing and to explore the way in which subjects make use of various characteristics of the game (like the cooperation index). As established in previous experiments (Hristova & Grinberg, 2004), different groups of subjects can be identified depending on their predominant cooperation patterns. Here, we want to further explore the differences between these groups by analyzing the specificity of their information acquisition strategies as evidenced by the eye-tracking technique.

The Prisoner's Dilemma Game

Prisoner's dilemma is a two-person game. The payoff table for this game is presented in Figure 1. The players simultaneously choose their move – C (cooperate) or D (defect), without knowing their opponent's choice.

R is the payoff if both cooperate (play C), P is the payoff if both defect (play D), T is the payoff if one defects and the other cooperates, S is the payoff if one cooperates by playing C and the other defects by playing D.

Figure 1. Payoff table for the PD game. In each cell the comma separated payoffs are the Player I's and Player II's payoffs, respectively

The payoffs satisfy the inequalities $T > R > P > S$ and $2R > T + S$. This structure of the payoff matrix of that game offers a dilemma to the players: there is no obvious best move. D is the strongly dominant strategy for both players because each player receives a higher payoff by choosing D rather than C whatever the other player might do. However, if both players defect, the payoffs (P, P) are lower than the payoffs (R, R) they would have received if both had cooperated (had chosen the dominated C strategy). By choosing to cooperate however, they have to trust that their opponent will also cooperate and take the risk of getting the lowest payoff – S (taken to be 0 in the present experiment).

Rapoport and Chammah (1965) have proposed the quantity $CI = (R–P)/(T–S)$, called *cooperation index* (CI), as a predictor of the probability of C choices, monotonously increasing with CI. In Figure 2 two examples of PD games with different CI – 0.9 and 0.1, respectively – are presented.

Figure. 2. Examples of PD games with different CI. The first game has a CI=0.1, the second one has CI=0.9.

Eye Movements

People see clearly only in the central area of the visual field and in order to cover larger visual areas perform frequent eye-movements (3-4 times per second). In general, eye movements consist of fixations (relatively stable eye positions, lasting approximately 200-300 ms) and saccades (fast transitions between two consecutive fixations). Visual information is acquired only during the fixations.

Decisions and choices depend on the processed information and this why studying information acquisition is so important to understand the strategies involved in game playing (Einhorn & Hogart, 1981; Lohse & Johnson, 1996). Eye movement recordings provide objective and quantitative evidence on what is being processed at the moment (Just & Carpenter, 1976; Duchowski, 2002). Eye-tracking data are used in a large number of studies of the cognitive processes (for a review see Rayner, 1998). The pattern of eye movements reveals what information is being looked at, for how long and how often. Position, duration and sequence of fixations can be used to study different tasks keeping in mind the important assumption that the information subjects are look at is closely related to the information they are processing. So, data about looking patterns could be used to gain knowledge about the thinking patterns.

To the best of our knowledge no eye-tracking studies of subjects playing PD games exist. A similar approach however was used in studying bargaining behaviour (Johnson et al., 2002). In these studies information acquisition patterns were studied using the Mouselab system in which the information is hidden in closed boxes on which subjects must click to see it.

Experiment

The first goal of this work is a descriptive one: to study the choice process in playing iterated PD games. We wanted to determine which information (payoffs, opponent's moves etc.) is more important for the subjects while playing PD games. The information acquisition patterns are studied using eye-tracking recordings.

The second goal of the experiment is to study the way CI is derived, if so, from the payoff matrix. In computing CI (or other possible indexes that could serve as predictors of cooperation rates), it is implicitly assumed that players pay attention to all payoffs in the payoff matrix in order to be able to extract the index. In most of the experiments exploring the influence of CI (see e.g. Rapoport & Chammah, 1965; Steele & Tedeschi, 1967; Jones et al., 1968; Oscamp & Perlman, 1965), each subject played one and the same PD game hundreds of times. In the latter case, subjects didn't need to pay attention to the payoffs all the time because the payoff matrix was the same. In the experiment presented here, we are interested in the actual computation of CI in a setup in which the payoffs are randomly generated and are different in each game.

The third goal is to try to find out how different strategies used by subjects are related to different information acquisition patterns.

Method

Participants 25 subjects with normal or corrected to normal vision took part in the eye-tracking experiment. All of the subjects were psychology students that participated in the experiment for course credits. Due to technical difficulties with calibration, the eye-tracking records of 6 subjects were discarded.

Eye Movements Recordings Eye movements were recorded using the ASL 501 eye-tracker with 60 Hz sampling rate. The light head mounted optics recorded the left eye movements. The centre of the pupil and the corneal reflection were tracked to determine the relative position of the eye. A magnetic head tracking equipment (Ascension

Flock of Birds) was used in order to compensate for the possible head movements and ensure sufficient precision of the measurements. Integration of the eye movements and head movements made it possible to compute point of regard on the computer screen.

The eye-tracker was calibrated using a 9-point grid. The accuracy of the gaze position record is about 0.5 degrees visual angle. Two computer systems were utilized. Intel Pentium 2.4 GHz PC ran the ASL software to calibrate and adjust settings on the eye tracker. Another Intel Pentium 1.8 GHz PC with 17" monitor was used for game presentation and running the Gaze tracker software for data recording and analysis.

Payoff Matrices A set of 50 PD different payoff matrices (containing an equal number of games with CI equal to 0.1, 0.3, 0.5, 0.7 and 0.9) was used in the experiment. Although CI is invariant with respect to the possible linear transformations of the payoff matrix, Oskamp and Perlman, 1965 claimed that the average payoff per trial is also important in predicting cooperation. Taking this into account, the payoff matrices were randomly generated with the payoff magnitudes kept within certain limits. T was between 22 and 77 points (mean 50), R was between 13 and 68 points (mean 41), P was between 1 and 60 points (mean 16). The S payoff is held constant (equal to 0). The games were presented randomly with respect to their CI.

Design Each subject played 50 PD games against the computer. The game was presented in a formal and a neutral formulation. On the interface, the moves were labeled '1' and '2'. Further in the paper, for convenience, we will continue to use cooperation instead of move '1' and defection instead of move '2'. Subjects were instructed to try to maximize their payoffs.

The computer used a probabilistic version of tit-for-tat that takes into account the two previous moves of the player and plays the same move with probability 0.8. The latter makes the computer's strategy harder to be discovered by the subject and in the same time allows the subject to impose her own strategy (and be followed by the computer).

After each game the subjects got feedback about their and the computer's choice and payoff in the current game. Subjects could also permanently monitor the total number of points they have won. They had no information about the computer's total score. This was made to prevent a possible shift of subjects' goal – from trying to maximize the number of points to trying to outperform the computer.

Procedure Each subject was tested separately. After calibration of the eye-tracker system, instructions were presented and each subject played 5 training games. After checking again the calibration (and fixing it if needed) the subject played the PD games sequence during which eye movements were recorded.

The game was presented on a 17" monitor. Each box containing payoffs or moves occupied about 1 degree visual angle on the screen. The distance between two adjacent boxes was at least 1 degree visual angle to ensure stable

distinction between eye-fixations belonging to respective zones.

Results and discussion

Areas of Interest We define 12 areas of the screen that are interesting in studying information acquisition during PD game playing. Each Area of Interest (AOI) contains the box in which the information is presented and a small region around it. The following AOIs were defined:

- Four AOIs containing the subject's possible payoffs: further these AOIs are referred to as T_S, R_S, P_S, and S_S.
- Four AOIs containing the computer's possible payoffs: further referred to as T_C, R_C, P_C, and S_C.
- Four AOIs containing the current game outcome: subject's move – M_S, computer's move – M_C, subject's payoff – Pf_S and the computer's payoff – Pf_C.

Dependent Variables The number of cooperative choices for each CI was used as a dependent variable characterizing the subjects playing behaviour.

The eye-tracking data were analyzed using two different measures of the attention paid to different AOIs. The first measure was the number of fixations in each AOI. It reflects the relative importance of the information presented in the AOI (Jacob & Karn, 2003). The second measure was the number of games in which a particular AOI was attented to at least once. The results from the two analyses were similar, so in the following we present only the first one.

Another measure that is commonly used is the duration of fixations in a given AOI. However, it seems to reflect the difficulty of information extraction rather than its importance (Jacob & Karn, 2003). Moreover, in the present experiment the information in each AOI was similar and the duration of fixations was almost the same. Therefore this metric was not used in the analysis of the data.

The information was gathered in two stages: before subject's choice (for T_S, R_S, P_S, S_S, T_C, R_C, P_C, and S_C AOIs) and after subject's choice (for M_S, M_C, Pf_S, and Pf_C AOIs). This was made in order to separate the data for the decision making process (before the game outcome).

Subjects with Different Strategies in Playing Although it is reasonable to cooperate more when R is high and P and T are relatively low, there is no guarantee that all of the subjects were able to take advantage of CI in their move choices. As the data from the present experiment show, confirming well-known previous results (see e.g. Rapoport & Chammah, 1965), there is a significant influence of CI on the cooperation rate – subjects cooperate more in PD games with higher CI (see Figure 3). But if we look more closely at the data, this trend is not followed by all of the subjects. As a cluster analysis based on the cooperation rate for each CI showed, two groups of subjects can be singled out. For the first group of 8 subjects (called further CI-based) the cooperation is a monotonously increasing function of CI; while for the second group of 11 subjects (called further

non-CI-based) such dependence is not observed (see Figure 3). The number of cooperative choices for each subject and each CI was analyzed in a repeated-measures ANOVA with the CI of the game as a within-subjects factor and the group (CI-based vs. non-CI-based) as a between-subjects factor. There is a significant interaction between the CI and the group ($p<0.001$). CI-based subjects were influenced by CI ($p<0.001$), while the influence of CI on cooperation rate for non-CI-based subjects is not statistically significant ($p=0.65$). Non-CI-based subjects showed an overall lower cooperation rate (20%) than the CI-based subjects (49%).
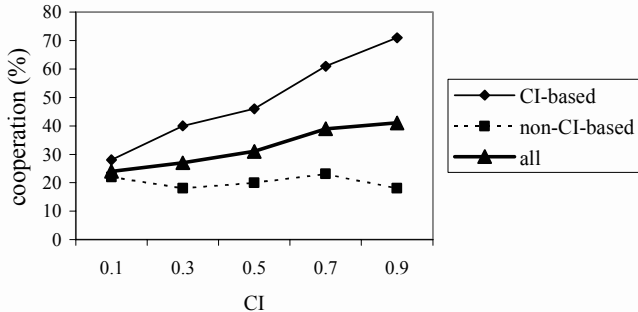
Figure 3. Mean cooperation for PD games with different CI: all subjects (*bold line*), CI-based group (*solid line*), non-CI-based group (*dotted line*).

In summary, on the basis of their cooperation patterns with respect to CI, two groups of subjects were identified. One group of subjects was influenced by the CI and the other was not. It was found that the CI-based group cooperated in average more than the non-CI-based one.

Attention to Subject's Payoffs (T_S, R_S, P_S, and S_S AOIs)
Eye-tracking data for the AOIs containing subject's payoffs were analyzed. Averaged data for all subjects are presented in Figure 4. It can be seen that subjects paid more attention to T and R payoffs. Subjects were looking at these payoffs twice more often than at P and S payoffs.
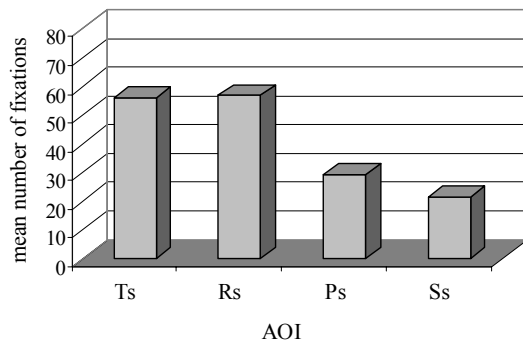

Figure 4. Mean number of fixations in AOIs containing subject's possible payoffs (T_S, R_S, P_S, and S_S).

A repeated measures ANOVA was performed with the AOI (T_S vs. R_S vs. P_S vs. S_S) as a within-subjects factor. The main effect of AOI is significant ($F(3, 54)=20.77$, $p<0.001$). Pairwise comparisons were used to test the difference between each pair of AOIs. All differences turned out to be statistically significant, except for the difference in

the mean number of fixations in the T_S and R_S zones. The finding is that subjects' attention was not equally divided to different payoffs.

Further, we were interested in the relation between playing behaviour and attention to payoff AOIs. Comparison between the mean number of fixations for both groups of subjects (the CI-based and non-CI-based) s presented in Figure 5. The difference is significant for R_S, P_S, and S_S AOIs ($p<0.05$). The conclusion can be made that the subjects from the non-CI-based group paid less attention to the payoffs than those from the CI-based.
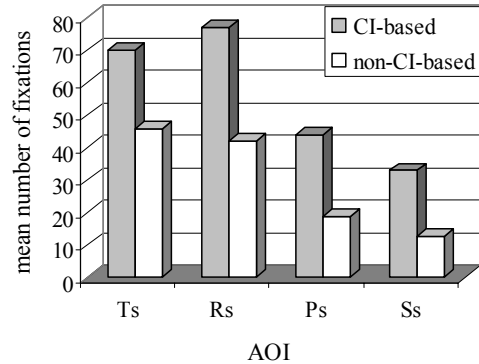

Figure 5. Mean number of fixations in AOIs containing the subject's possible payoffs (T_S, R_S, P_S, and S_S): CI-based group (*grey bars*) and non-CI-based group (*white bars*).

All subjects paid more attention to T and R payoffs compared to P and S payoffs. There is also a relation between the playing behaviour and the looking patterns. As expected, the subjects from the CI-based looked more often at their possible payoffs.

Transitions between AOIs The processing of possible payoffs is not related only to the number of times each payoff was attended to. It is also linked to the pattern of transitions between payoffs' AOIs. Transitions are used as an indicator of performed comparisons between payoffs.
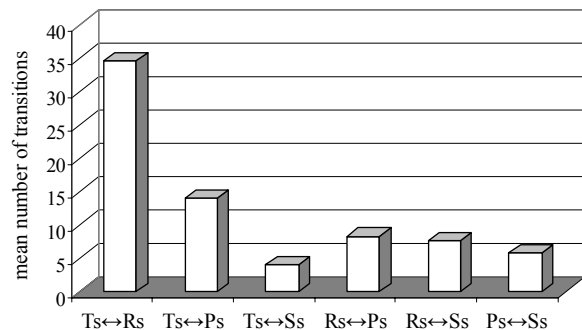

Figure 6. Mean number of transitions between the corresponding AOIs (in both directions): e.g. $T_S\leftrightarrow R_S$ stands for transitions between T_S and R_S AOIs, and $Ts\leftrightarrow Ps$ – for transitions between T_S and P_S AOIs.

Eye-tracking data for transitions are presented in Figure 6. Most transitions were made between T_S and R_S,

and between T_S and P_S AOIs. It can be hypothesized that subjects were comparing T and R payoffs, also T and P payoffs. Rapoport (1965) proposes that CI is computed as (R-P)/T. Data form the current experiment show that CI might be computed e.g. as R/T – P/T. The latter is mathematically equivalent to CI and in the same time allows for a two-step evaluation: first R and T, and then P and T.

These findings apply especially to the CI-based subjects (see Figure 7). Non-CI-based subjects very rarely compared T and P payoffs. Transitions between T_S and P_S AOIs were statistically less than the transitions between T_S and R_S AOIs (p=0.022). In fact these subjects were not able to estimate the CI as they were not paying attention to all of the payoffs and relations between them.
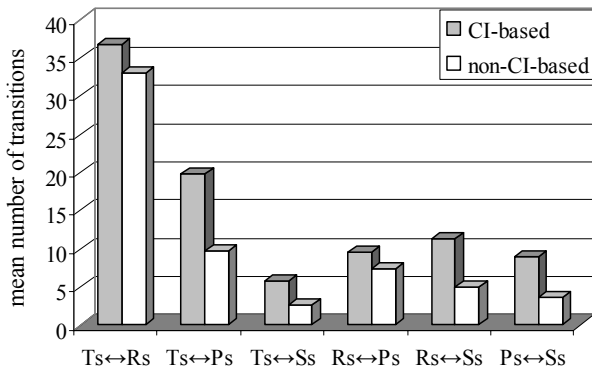

Figure 7. Mean number of transitions between the corresponding AOIs for the CI-based subjects (*grey bars*) and non-CI-based subjects (*white bars*). $T_S \leftrightarrow R_S$ stands for transitions between T_S and R_S, AOIs; $T_S \leftrightarrow P_S$ – for transitions between T_S and P_S AOIs; etc.

Attention to Computer's Payoffs (T_C, R_C, P_C and S_C AOIs) As mentioned above, playing that is based on all the available information and is inline with the game theory reasoning, should take into account not only the player's payoffs but also his opponent's possible payoffs. Eye-tracking data show that considerably less attention was devoted to the computer's payoffs (see Figure 8). Fixations again are more numerous for the R and T opponent's payoffs.
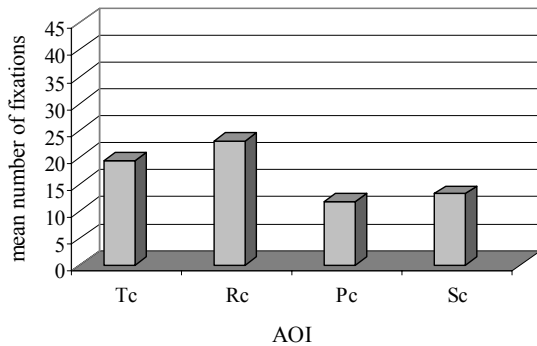

Figure 8. Mean number of fixations in AOIs containing computer's possible payoffs (T_C, R_C, P_C, and S_C).

The difference in the mean number of fixations between subjects with different strategies is significant for all of the computer's payoffs – T_C, R_C, P_C, and S_C (p<0.05 for all comparisons) (see Figure 9). The non-CI-based subjects paid almost no attention to the computer's payoffs – each payoff was attended less than 10 times for 50 PD games. These subjects ignored completely their opponent's possible payoffs. CI-based subjects paid less attention to the computer's possible payoffs than to their own possible payoffs. Still, computer's payoffs got considerable attention – especially R_C and T_C AOIs (see Figure 9).
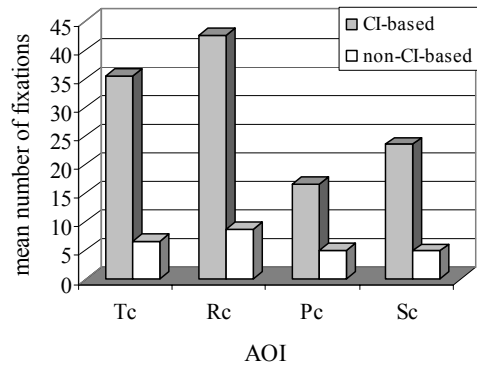

Figure 9. Mean number of fixations in AOIs containing computer's possible payoffs (T_C, R_C, P_C, and S_C) for the both groups of subjects: CI-based (*grey bars*) and non-CI-based (*white bars*).

Attention to Game Results (M_S, Pf_S, M_C, and Pf_C AOIs)
The number of fixations in AOI related to the game outcome (points obtained and moves made) is presented in Figure 10. Subjects paid less attention to the computer's result and move than to their own. The difference in the mean number of fixations between subjects with different strategies is significant for M_C AOI (p=0.048). The subjects with non-CI-based strategy paid more attention to their opponent's move than the subjects from the CI-based group. This is consistent with the hypothesis that the subjects from the non-CI-based group relied more on this information than the subjects from the CI-based group.
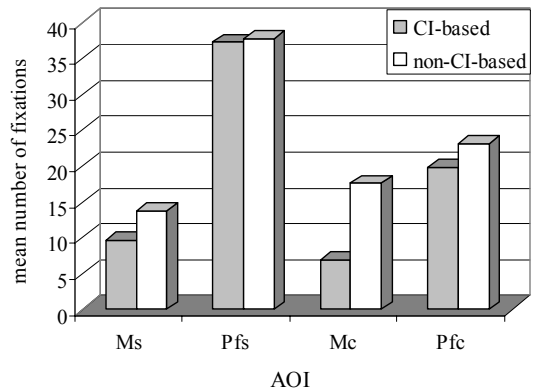

Figure 10. Mean number of fixations in AOIs containing game results (M_S, Pf_S, M_C, and Pf_C): CI-based group (*grey bars*) and non-CI-based group (*white bars*).

From the presented in Figure 10, it might seem that subjects did not pay much attention to the game results. However, it should be noted that in the game interface used, there was a different way of gathering information about the game outcome. After a move choice, the payoffs corresponding to the game outcome changed their color in the payoff matrix. This should be corrected for in future experiments.

Conclusions

In the present paper we studied the information acquisition patterns of subjects playing PD game by means of eye-tracking recordings. The method used is applied for the first time for the investigation of the details of the decision making process in PD games.

The analysis of the data showed that subjects do not pay equal attention to all of their possible payoffs – they were mainly interested in the T and R payoffs (payoffs for unilateral defection and for mutual cooperation). The opponent's payoffs were looked at rarely. These results challenge game theory axioms of access to complete knowledge about the games and are in favor of the bounded-rationality framework for decision making analysis.

On the basis of their playing behaviour two groups of subjects were identified. Part of the subjects showed a clear dependence on the game cooperation index – they played more cooperatively with increasing CI. The other part of the subjects cooperated less and did not show any dependence on CI. The comparison of the eye-tracking data for both groups reveals different patterns of information processing consistent with the latter behavioural differences.

The subjects from the first group (CI-based) paid more attention to the payoffs. They compared predominantly the T and R payoffs and to a lesser extent T and P payoffs. These data support our hypothesis that the cooperation index, usually presented as (R-P)/T, might be evaluated by subjects as R/T – P/T.

The second group of subjects (non-CI-based) looked less frequently at the payoffs than the first group and almost completely ignored the opponent's payoffs. They made comparisons predominantly between T and R and only incidentally between T and P. On the other hand, this group paid more attention to the computer's moves. These two findings are evidence that the subjects from this group didn't made use of CI, which is completely consistent with the behavioural data. Their strategy was predominantly based on the opponent moves.

The results obtained demonstrate that eye-tracking data combined with behavioural data can shed light on the different strategies employed by subjects during playing and on what part of the available information subjects base their decisions.

Acknowledgments

References

Axelrod, R. (1984). *The evolution of cooperation*. Basic Books.

Camerer, C. (2003). *Behavioral game theory: experiments on strategic interaction*. Princeton University Press.

Camerer, C., Ho, T.-H., & Chong, J. (2002). Sophisticated EWA: learning and strategic teaching in repeated games. *Journal of Economic Theory*, *104*, 137-188.

Colman, A. (2003) Cooperation, psychological game theory, and limitations of rationality in social interaction. *Behavioral and Brain Sciences*, *26*, 139-198.

Duchowski, A. (2002). A breadth-first survey of eye tracking applications. *Behaviour Research Methods, Instruments, and Computers*, *1*, 1-16.

Einhorn, H., & Hogarth, R. (1981). Behavioral decision theory: Processes of judgment and choice. *Annual Review in Psychology*, *32*, 53-88.

Erev, I., Roth, A. (2001). Simple reinforcement learning models and reciprocation in the Prisoner's dilemma game. In: Gigerenzer, G., Selten, R. (Eds.), *Bounded rationality: the adaptive toolbox*, Cambridge, Mass. MIT Press.

Hristova, E., & Grinberg, M. (2004). Context effects on judgment scales in the Prisoner's dilemma game. *Proceedings of the 1st European Conference on Cognitive Economics.*

Jacob, R. & Karn, K. (2003). Eye tracking in human computer interaction and usability research: Ready to deliver the promise. In: Hyona, J., Radach, R., & Deubel, H. (Eds.), *The mind's eye: cognitive and applied aspects of eye movement research*. Elsevier Science BV.

Johnson, E., Camerer, C., Sen, S., & Rymon, T. (2002). Detecting failures of backward induction: monitoring information search in sequential bargaining. *Journal of Economic Theory, 104,* 16-47.

Jones, B., Steele, M., Gahagan, J., & Tedeschi, J. (1968). Matrix values and cooperative behavior in the Prisoner's dilemma game. *Journal of Personality and Social Psychology, 8,* 148-153.

Just, M., & Carpenter, P. (1976). Eye fixations and cognitive processes. *Cognitive Psychology, 8*,441-480

Lohse, G. & Johnson, E. (1996). A comparison of two process tracing methods for choice tasks. *Organizational Behavior and Human Decision Processes*, *68*, 28-43.

Macy, M., & Flache, A.(2002). Learning dynamics in social dilemmas. *PNAS, 99,* 7229-7236.

Oskamp, S., & Perlman, D. (1965). Factors affecting cooperation in a Prisoner's dilemma game. *Journal of Conflict Resolution, 9,* 359-374.

Rapoport, A. (1967). A note on the 'index of cooperation' for Prisoner's dilemma. *Journal of Conflict Resolution, 11,* 100-103.

Rapoport, A., & Chammah, A. (1965). *Prisoner's dilemma: a study in conflict and cooperation*. Univ. of Michigan Press.

Rapoport, A., & Mowshowitz, A. (1966). Experimental studies of stochastic models for the Prisoner's dilemma. *Behavioral Science, 11,* 444-458.

Rayner, K. (1998). Eye movements in reading and information processing: 20 years of research. *Psychological Bulletin, 124,* 372-422.

Simon, H. (1955). A Behavioral model of rational choice. *Quarterly Journal of Economics, 69,* 99-118.

Steele, M. & Tedeschi, J. (1967). Matrix indices and strategy choice in mixed motive games. *Journal of Conflict Resolution, 11,* 198-205.