Babeş-Bolyai University
Faculty of Psychology and Educational Sciences
Doctoral School of „Education, development, cognition”

PhD Thesis

Strategic Adaptation in Iterated Decisions

Summary

Scientific advisor:
prof. dr. Vasile Liviu PREDA

PhD candidate:
PÉNTEK Imre

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Contents of Thesis[1]

[1] We are presenting the whole content of the thesis. References to chapters in this long abstract refer to the chapters of the thesis. Section numbering of the long abstract does not necessarily reflect the structure of the thesis. Similarly the table and figure numbering dose not necessarily reflect the numbering in the thesis.

Key-words: strategic adaptation, iterated decisions, behavioral decision making, behavioral game theory, metacognition, educational methods, individual differences, implicit processing, simulation methods, perception of probabilities, frequency processing

Abstract

In dynamic environments probabilistic information are the most important in the evaluation of risks and the selection of a decisional strategy. The aim of the study is the analysis of strategic adaptation in iterated decisions, in which probabilistic information is not pre-calculated. In these situations people approximate probabilities based on direct experience. Using important findings of behavioral decision making and game theory, we conducted four experiments to evaluate strategic adaptability and probabilistic information use in different situations. Results showed that people are sensible to minor variations in the probabilistic environment, and they can successfully integrate probabilistic information in the adaptation of decisional strategies. These abilities were most evident under conditions of direct experience.

1. Introduction

We live in a society of accelerated changes. We live in an era of unprecedented social, economical, climatic, and technological changes. These changes expose us naturally to different kinds of risks, which are more and more difficult to evaluate and avoid. As the German sociologist Ulrich Beck (1998) stated, we are living in the “society of risk”, in which for the first time in the history of humankind the majority of risks are anthropogenic. Neither the individual nor the society can ignore these auto-induced risks. We can relate to these risks by serious reflection and adaptation, but, as we can learn exactly from these anthropogenic changes, adaptation is not unilateral. Any behavioral action will reverberate to some extent on humanity. The environment, be it ecological, economic or social is not immune to human behavior, because mankind, with or without intention, multiplied its effect on the environment, changing it radically, without fully understanding the consequences that will reverberate upon itself.

Reflecting to these risks means at least three things: (1) evaluating the impact of these changes; (2) evaluating the probability of these changes; and last but not at least (3) analyzing the way in which people perceives risks in there environments. Nassim Nikolas Taleb (2007), in his book “The Black Swan”, argues that statistical methods of evaluating risks have several limitations. If an event could have disastrous consequences and the probabilistic structure of the environment is poorly known, then we should be very cautious with the evaluation of risks. The 2007-2010 financial crises showed that risk assessment made by professionals can be severally biased and that these biases on a large scale can lead to huge financial losses. Institutional globalizations, Taleb argues, “creates interconnected fragilities”, and at the same times it crates the illusion of stability. These illusions can misguide professionals and laypeople as well in the assessment of risks.

We analyzed strategic adaptation in iterated decisions, with the following premises in mind: (1) people seldom analyze pre-calculated probabilities—they usually approximate probabilities based on their accumulated experiences; (2) probabilities in the real world are not static—they generally change dynamically; (3) the probabilistic structure of the environment is not independent of human actions; generally, strategic interdependence characterizes the probabilistic structure of the decisional environment.

The thesis is structured around five main chapters. In chapters 2 and 3 the main perspectives of strategic adaptation are presented by analyzing theories of strategic decision making in problem-solving, statistical theories of decision making, and fast and frugal heuristics.

The main question of chapter 4 is how people use probabilistic information in decision making under conditions of direct experience. Our innovative simulation study made it possible to evaluate the metacognitive knowledge of participants regarding the probabilistic structure of the decisional environment, and to analyze the relation between decision time and the decisions optimality.

In chapter 4 we tried to analyze mechanisms of strategic adaptation when the probability structure of the decisional environment is not influenced by the participant's decisions. In chapter 5, in a quasi-experiment, we tested detrimental effects of strategic adaptation to abstract mathematical problems in educational settings. We also tested adaptation to real world problems and its relation to metacognitive aptitudes and analytic intelligence. This study demonstrated the same effects found in the previous experiment in educational settings.

The most important part of the thesis (chapter 6) describes a series of three experiments aimed at analyzing strategic adaptation under conditions of strategic interdependence. These experiments tested predictions of behavioral game theory in different experimental settings using various methods of behavioral analysis in prisoner's dilemma, public goods game, and p-beauty contest game with real or simulated opponents.

In dynamic environments probabilistic information are the most important in the evaluation of risks and the selection of a decisional strategy. The aim of the study is the analysis of strategic adaptation in iterated decisions, in which probabilistic information is not pre-calculated. In this situations people approximate probabilities based on direct experience. Using important findings of behavioral decision making and game theory, we conducted four experiments to evaluate strategic adaptability and probabilistic information use in different situations.

2. Mechanisms of Strategic Adaptability in Probabilistically Static Situations

Base-rate literature shows that people tend to overweight specific sources of information at the expense of other more global sources of information (base-rates) even when base-rates have high predictive values. Empirical studies show that base-rates are not totally ignored and their degree of use depends on task structure and representation (Koehler, 1996). Most of the empirical studies used paper-and-pencil tests to demonstrate the phenomenon. Critics argued that base-rate neglect is largely due to the fact that most of the test presents the problems in probability formats. Gigerenzer and Hoffrage (1995) showed in several studies that presenting the problems in frequency format can alleviate base rate neglect to some extent. In realistic decision environments, however, probabilities are rarely found already calculated. People experience event probabilities in real-world situations through trial-by-trial response feedback and their perception of frequencies largely affect decision strategies.

We have designed a computer-based economic simulation in which subjects directly experience event frequencies, and in which discrete nonverbal choices are made. This methodology allowed us to examine indirectly the extent to which base rate information is used by subjects. Reaction times and self-reported event frequencies were recorded. Results shows that base-rate neglect persists in ecologically valid situations, even if self-reported event frequencies are accurate. Reaction time was significantly smaller in the case of Bayesian decisions compared to sub optimal decisions. Subjects demonstrated adaptive strategic trend over the 400 trial, but only few of them achieved optimal strategy. Consequences of these results are discussed for evolutionary theories of base rate neglect. We will argue that results suggest implication of two reasoning systems in decisional processes.

Base-rate error has been a mater of considerable dispute. The major debate focused on the question whether base rate fallacy is or is not a real error in decision making. Empirical studies show that base rates are used to different extent depending on situational and task variables (Goodie and Fantino, 1999). Critics (Koehler, 1996) argued that the majority of studies used tasks rarely found in real-word environments. Some studies (Lindeman et al., 1988; Medin & Edelson, 1988), however, focused on situations where base-rates are directly experienced through trial-by-trial response feedback. Most of these studies faced one of the following two problems: (1) number of trials was limited; (2) the task's face validity has been too low. We have found only a few studies (ex. Goodie 1999) directed toward the mechanisms underlying base rate neglect under direct condition. Our study differs in two ways: (1) we tried to construct a task with higher face validity and higher ecological validity without compromising internal validity; (2) our study focused especially on mechanisms underlying base-rate neglect under direct condition.

2.1. ***Methods***

We have developed a computer simulation of a simplified economic market situation in which subjects could choose to invest in one of two products that had to be sold on the next day. Subjects were told that prices vary $10 each day, and that, when the price of one product raises, the price of the other product will necessarily drop.

Table 1 Incidence table for 100 trials in the two conditions of the experiment.

Base rate: 67% Cue accuracy: 67%

		Price rise prediction: gold	Price rise prediction: oil	
Price rise	**gold**	45	22	67
	oil	11	22	33
		56	44	100

p(G|G)=33/50=0.67,
p(G|O)=17/50=0.33

Base rate: 67% Cue accuracy: 50%

		Price rise prediction: gold	Price rise prediction: oil	
Price rise	**gold**	33	33	≈67
	oil	17	17	≈33
		50	50	100

p(G|G)=45/56=0.80,
p(G|O)=22/44=0.50

Subject had one clue to make their decision: an economic advice which was 50% respectively 67% accurate in the two situations. Base-rate remained stable across situation the price of one of the product raised 67% of the time where as the price of the other product 33% of the time (table 1).

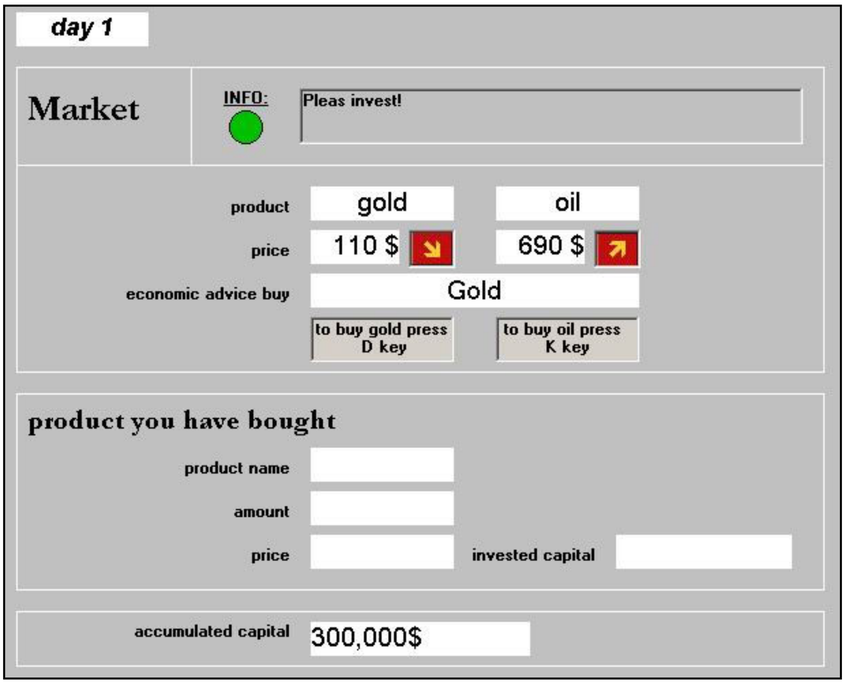

Figure 1 The principal interface of the simulation used in the experiment.

Participants were randomly assigned to one of the two conditions and they participated in 2 experimental sessions, each consisting of 200 trials.

2.2. ***Results***

Performance steadily became more adaptive over time in all conditions where a normative strategy can be identified. The following exhibits depict the proportion of trials on which subject matched the cue, buying gold in the presence of buy gold advice ore or buying oil in the presence of buy oil advice (figure 2 and figure 3).

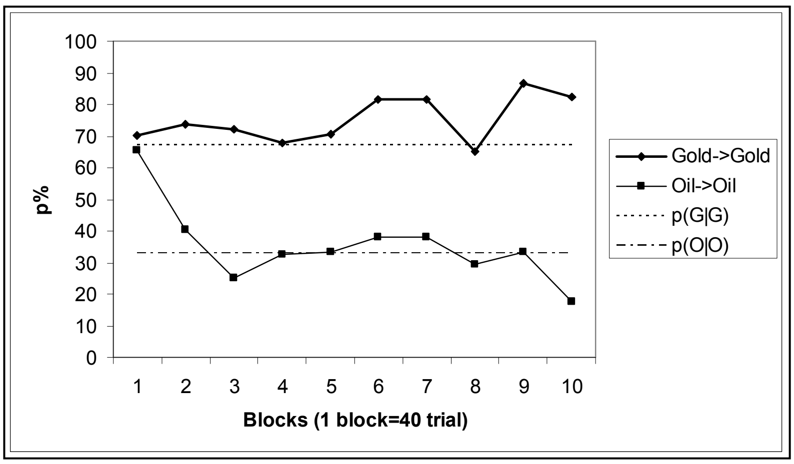

Figure 2 Investment choice proportion across the experimental blocks as a function of economic prediction in the 67%/50% base rate / cue accuracy condition.

To assess the statistical significance of these effects, a three-way, 2x2x2 Analysis of Variance was conducted. (2 levels of cue accuracy, varied between subjects; 2 sessions, a repeated measure factor; 2 cues, gold or oil, a repeated measure factor).

Significant cue accuracy effect suggests that subjects paid more attention to base-rates when cue accuracy was less informative.

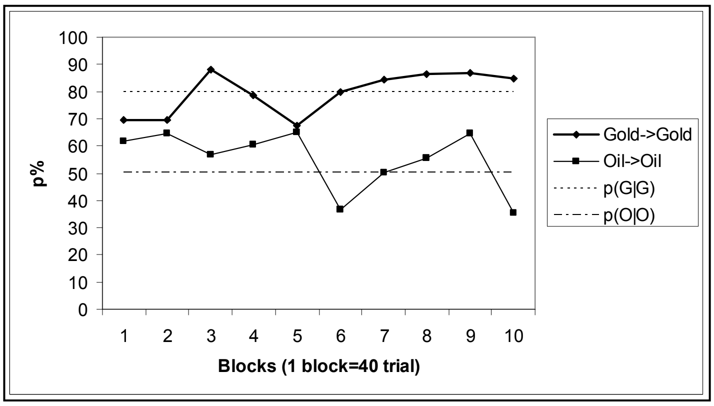

Figure 3 Investment choice proportion across the experimental blocks as a function of economic prediction in the 67%/50% base rate / cue accuracy condition.

Significant cue effect suggests that subjects did not completely ignore base rates; however, few of them reached optimality. Participants' demonstrated probability matching in both conditions, overshooting was present in just few cases. The general increase in matching gold clue over time, while matching oil clue generally declined, is reflected in the statistically significant session x cue interaction (table 2).

Table 2 ANOVA table of choice proportion

Source	DF	MS	F
Cue Accuracy	1	2119.797	11.121[a]
Cue	1	14390.702	29.067[a]
Cue x Cue Accuracy	1	1895.623	3.829
Session	1	0.329	0.004
Session x Cue Accuracy	1	2.034	0.026
Session x Cue	1	1877.164	16.689[a]
Session x Cue x Cue Accuracy	1	33.945	0.302

[a]p<0.01

Comparing reaction time of choices consistent with Bayesian standards to reaction time of suboptimal choices we have found that RT of Bayesian choices are significantly lower, regardless of accuracy of the clue. These findings suggest that different kinds of cognitive processes could be involved in Bayesian and non Bayesian choices (figure 4).

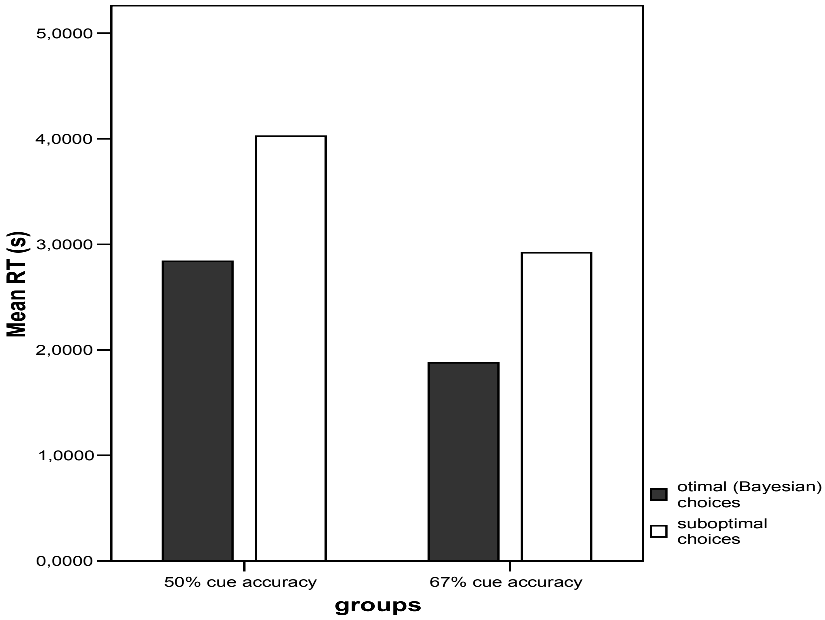

Figure 4 Mean reaction time by cue accuracy and choice optimality.

2.3. ***Conclusions***

Our finding suggests that base-rates information are underweighted under direct experience even in tasks with higher ecological validity. Reaction time evidence suggests that Bayesian choices are produced by more rapid, implicit evolutionary older processes. Base rates that are directly experienced may be accorded more weight than ones that are indirectly experienced because they invoke an implicit rather then an explicit learning system. Information learned implicitly may be more easily accessed by implicit decisional processes. Explicit processes could be accountable for rationally underweighting base rates when base-rate change more frequently then cue accuracy. Explicit processes could explain the choice pattern differences between human and non-human behavior. Probability matching in humans found in this experiment is not mirrored by comparable responses in other animals. Pigeons maximize reinforcements under such circumstances (Hartl & Fantino, 1996).

3. Perception of the Opponent's Strategy and Adaptation of Decisional Strategies in Iterated Dynamic Interactions

Three studies were performed concerning the strategic adaptability in dynamic interaction. The three experiments focused on three strategic games in which the probabilistic environment dynamically changed as the game evolved. In the first experiment we tested predictions of game theory concerning strategic behavior of players in the iterated public goods game (presented only in the extended version). The second experiment focused on differences in strategic behavior between inter-individual and inter-group play in the iterated p-Beauty Contest game. In the last experiment based on our findings in the previous two experiments we implemented a methodology of simulated opponent to test strategic adaptation when the opponent changes its strategy radically.

3.1. *Strategic Adaptability In The Iterated P-Beauty Contest (P-BC) Game: A Comparison Study Of Inter-Group And Inter-Individual Game Strategies*

The aim of this study was to analyze the strategic adaptation of groups playing against each other (inter-group game) comparing and to compare how it differs from individuals playing against each other (inter/individual game). We hypostasized that deliberation processes in the groups will foster reflective thinking and metacognitive questioning and that would lead to more thinking steps taken before the selection of a strategy compared to inter-individual play.

In the iterated p-BC game players simultaneously have pick an integer between 0 and 100. The winner of the contest is the player(s) whose number is closest to p times the average of all numbers submitted (where p is a fraction in our case 1/2).

Participants (38 undergraduate students) played 10 rounds of p-BC game. Participants were randomly assigned to inter-group (groups of 3participants) or inter-individual condition.

3.1.1. **Results**

The submitted numbers in both experimental conditions evolved toward the Nash equilibrium (0). The strategic behavior in the first rounds did not differed significantly between the two conditions. Groups compared to individuals haven't used better strategies or more thinking steps in the first three forums, but as the game evolved groups adapted much faster. After just six rounds (as shown on figure 5) all the groups selected the Nash strategy from this point forward. On the contrary individual players used increasing number of thinking steps, but just two players selected the equilibrium strategy (in round 5 and round 6 respectively).

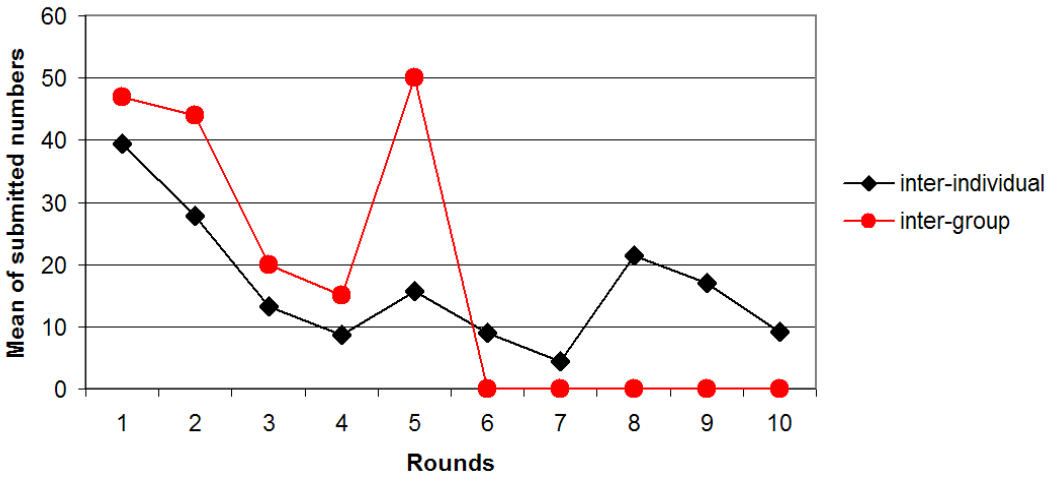

Figure 5 Evolution of submitted numbers in the case of inter-individual and inter-group play.

3.1.2. **Discussions**

Results confirmed that (1) neither groups nor did individual players selected the equilibrium strategy in the first rounds as predicted by game theory. (2) Players showed significant trends of adaptation, increasing the number of thinking steps across the round, but groups adapted much faster compared to individual players. Reflective thinking could have been facilitated by group deliberation increasing the thinking steps taken before the selection of a strategy. (3) As the behavior of the players constitute the stimuli of the other players the experimental control is limited. To overcome these limitations of the classic game theoretical paradigm in the next experiment we used the method of simulated opponents in which the behavior of the simulated player can be fully controlled by the experimenter.

3.2. ***Adaptation of Strategic Decisions in the Iterated Prisoner's Dilemma***

Experimental and stimulation studies of the prisoner's dilemma focus mostly on strategic interaction between competing individuals or competing computer programs employing different strategies. Both methods have some limitations. By studying competing human participants, researchers can only study spontaneously arising behaviors. Simulation studies have the major advantage that researchers can simulate a virtually infinite variety of competing pure or mixed strategies, but it is unclear to what extent the results can be generalized to human interactions.

In series of studies Axelrod (1979) explored the efficiency of computer programs employing different strategies in two IPD tournaments. The prisoner's dilemma is one of the well-known dilemmas in game theory. In the classic form of the prisoner's dilemma (depicted in its normal form in table 4) "two suspects are arrested by the police. The police have insufficient evidence for a conviction, and, having separated both prisoners, visit each of them to offer the same deal. If one testifies (defects from the other) for the prosecution against the other, and the other remains silent (cooperates with the other), then the betrayer goes free, and the silent accomplice receives the full 10-year sentence. If both remain silent, both prisoners are sentenced to only six months in jail for a minor charge. If each betrays the other, each receives a five-year sentence. Each prisoner must choose to betray the other or to remain silent. Each one is assured that the other would not know about the betrayal before the end of the investigation. How should the prisoners act?"

Table 3 The classical prisoner's dilemma in its normal form

	Prisoner B stays silent	***Prisoner B betrays***
Prisoner A stays silent	Each serves 6 months	Prisoner A: 10 years Prisoner B: goes free
Prisoner A betrays	Prisoner A: goes free Prisoner B: 10 years	Each serves 5 years

Axelrod (1979) found that the most efficient strategies have similar behavioral characteristics (nice, retaliating, forgiving, non-envious) and that the tit for tats (TFT) strategy, submitted by Rapoport, proved to be the most successful even if it only repeated the strategy used by the opponent in the previous round.

By examining experimental and simulation studies we found that there are at least four important limitations of these paradigms: (1) by examining competing computer programs it is difficult to generalize to the strategic behavior of human subjects, considering that humans rarely employ pure strategies; (2) by examining competing human participants researchers can not manipulate important independent variables. They can only study spontaneously arising situation. Players are strategically interdependent, thus they act as stimuli to each other, without the possibility of intervention of the experimenter; (3) researchers can efficiently control and manipulate variables, when studying human participants playing against computer programs, but the behavior of the programs can rarely mimic the most important properties of the strategic behavior of human subject's; (4) in the majority of the studies performed, the strategies against participants played were pure strategies. Just few studies were interested in how humans adapt to the opponent's strategic change.

We tried to combine these methods by studying how human subjects adapt there strategy when playing again simulated agents employing different stochastic strategies or when these agents change there strategies. Stochastic strategies are mixed strategies in which one player's strategy does not deterministically influence the opponent's response. The strategy of one player only influences the probability of cooperation of the opponent in the next round. In order to simulate the behavior of a human opponent, we studied participants playing against a simulated agent employing non-stationary stochastic strategies.

Participants (101 undergraduate students) played 190 rounds of iterated repeated prisoner's dilemma against a computer employing successively two kinds of probabilistic strategies. Using a 2x2 factorial design we tried to determine how the order of the opponent's strategy (TFT, WSLS vs. WSLS, TFT) and knowledge about the opponent (human vs. computer) affect speed of adaptation after a strategic change of the opponent. Decision times were recorded for all the decisions

The game was presented on Pentium computers with 17'' monitors. The Visual Basic program that was used to present the game also recorded participants' responses and RT's. Participants were tested in 4 groups (presented in table 5).

Table 4 Experimental design.

	Computer's strategy: TFT-WSLS	**Computer's strategy: WSLS-TFT**
Believed opponent: computer	N=23	N=27
Believed opponent: human	N=27	N=24

The computer simulated opponents implementing two kinds of strategies counterbalanced for the order of the strategies in the two experimental conditions as depicted in table 6.

Table 5 The opponent's simulated strategies in the two experimental conditions.

	90 rounds	**10 rounds**	**90 rounds**
Condition 1	Probabilistic TFT	P(cooperation)=.25	Probabilistic WSLS
Condition 2	Probabilistic WSLS	P(cooperation)=.25	Probabilistic TFT

In both groups the initial probability of cooperation was .50. In the subsequent rounds the computer adjusted the probability of cooperation with increments of .25 based on the opponents' response and the strategy employed (as presented in table 7).

Table 6 Behavioral differences between TFT and WSLS strategies.

Round *n*		Response of the computer in round n+1	
Computer	**Participant**	**TFT**	**WSLS**
C	C	C	C
D	C	**C**	**D**
C	D	D	D
D	D	**D**	**C**

C-cooperate, D-defect

3.2.1. **Results**

Results show that human participants adapted their strategies to the opponent's strategy. Across the first three blocs, participants in both experimental conditions significantly increased the selection proportion of the strategy that fostered cooperation. As depicted on figure 6, after the opponent's strategy change, the probability of cooperation after defection started to change dramatically to foster cooperation.

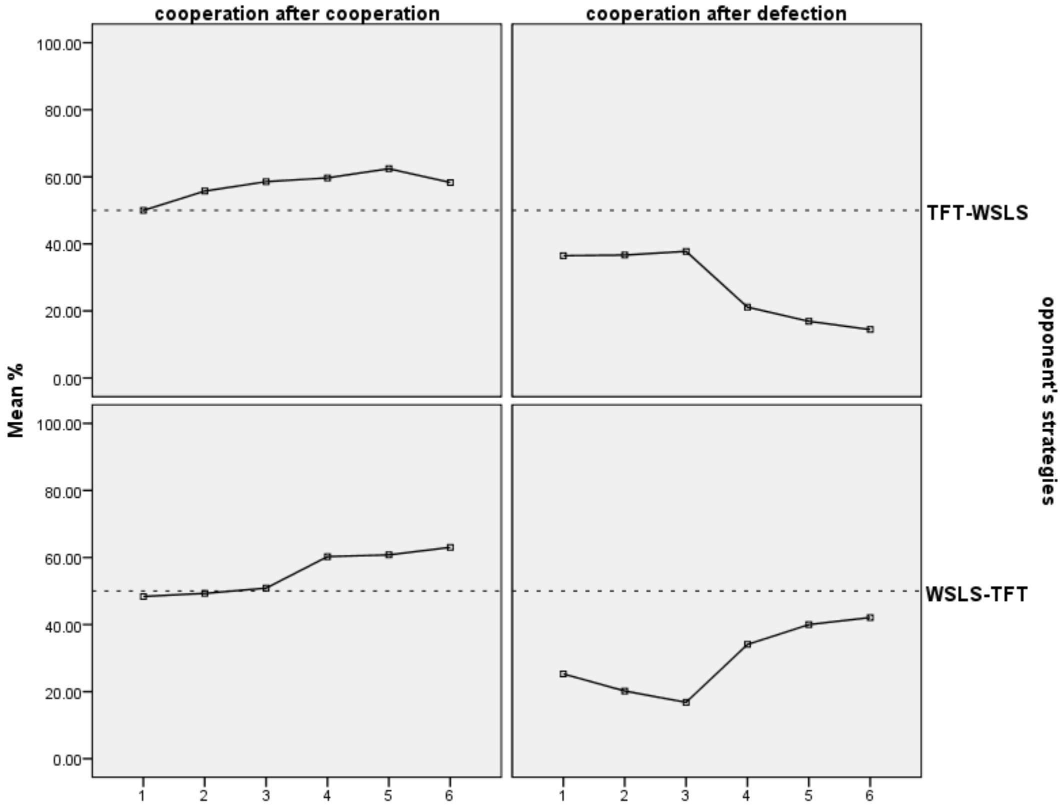

Figure 6 Evolution of cooperation probabilities as a function of opponent's strategies.

Between the two strategies implemented by the opponent, reaction to cooperation after defection was the most important difference, as probabilistic TFT increased the cooperation probability, while probabilistic WSLS decreased cooperation probability in this case.

Analyzing the scores obtained by participants, we have found that scores have a bimodal distribution. In order to found the sources of this major performance differences we compared adaptation trends as a function of scores obtained.

Interestingly the major source of the performance differences, as depicted in figure 7, was the speed of adaptation, not the strategies selected "ab ovo". Compared to the high score group participants with low scores showed almost no signs of adaptation cooperation rates remaining almost unchanged even if the opponent's strategy changed radically.

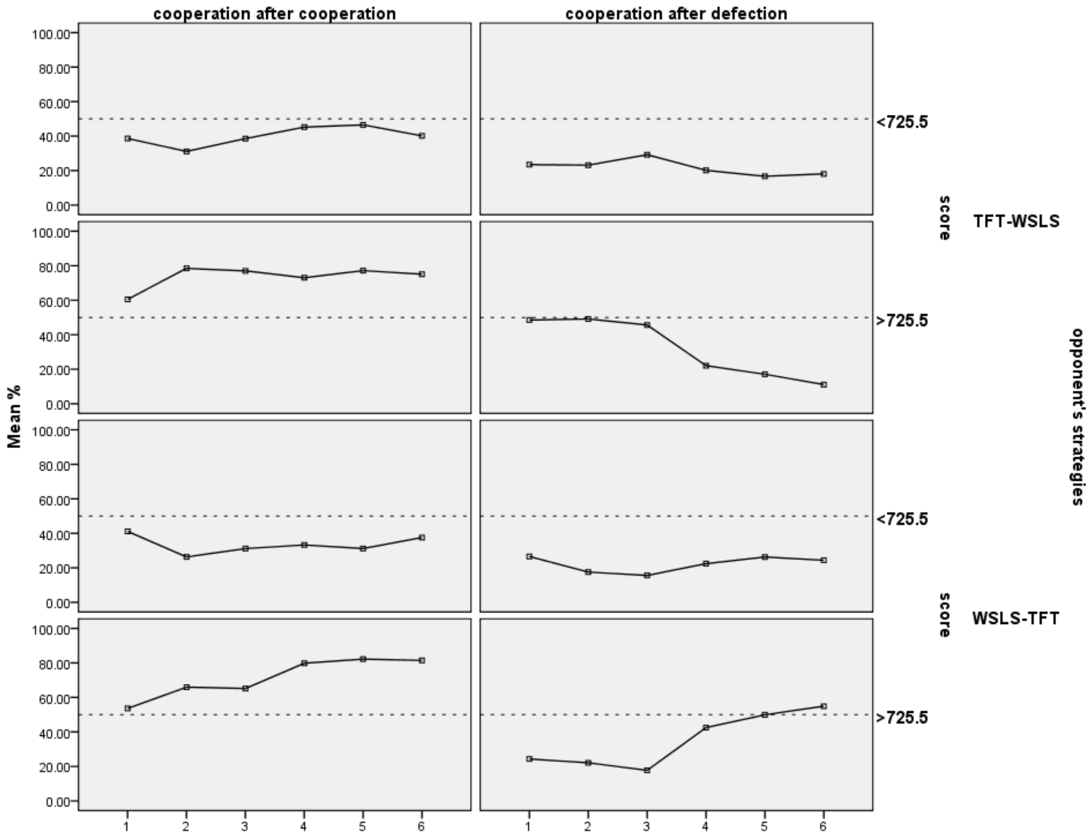

Figure 7 Evolution of cooperation probabilities as a function of opponent's strategies and the nature of believed opponent.

3.2.2. **Discussions**

Results confirmed the following conclusions: (1) Participants can perceive complex strategic pattern of the opponent and can adapt there strategies when the opponents strategies significantly change. (2) Performance of the participants has a bimodal distribution. (3) Good performance is clearly determined by the ability to adapt to the changing strategy of the opponent. (4) Beliefs about the opponent (computer/human) do not affect significantly the strategic behavior of the participants.

4. Conclusions

Starting from three premises, derived form realities of contemporary society (see “society of risk” Beck, 1998 and Marga, 2007) and risk related behavioral patterns, in our thesis we analyzed processes of strategic adaptation in iterated decisions. The three premises were: (1) people seldom analyze pre-calculated probabilities—they usually approximate probabilities based on their accumulated experiences; (2) probabilities in the real world are not static—they generally change dynamically; (3) the probabilistic structure of the environment is not independent of human actions; generally, strategic interdependence characterizes the probabilistic structure of the decisional environment.

Our research strategy was to gradually raise the complexity of the experimental situation with each experiment. At the same time we tried to assure an optimal tradeoff between experimental control and the ecological validity of the studies. Results of the first experiments showed that in probabilistically static decisional environment base rate use vary with task structure. In the case of realistic tasks with high ecological validity, base rates have a higher impact on decisions (exceeding probability matching with 7-17.5%). People are sensitive to statistical variations in the decisional environment, like the variations of predictive validity of case clues. Similarly, people do not neglect base rates; they just do not consider it with the same weight as they consider clue validities. Decision times showed the role of automatic processing in the decision making, as Bayesian decisions had been reached in significantly lower time then suboptimal decisions. At the same time we found no correlation between evaluations of conditional probabilities and decisions made, which also suggest that important parts of decision making processes are automatic.

In chapter 6, using the p-beauty contest game, we analyzed the strategic adaptation of groups playing against each other (inter-group game), and we also compared them to individuals playing against each other (inter/individual game). Results confirmed that neither groups nor individual players selected ab ovo the equilibrium strategy as predicted by game theory. Players showed significant trends of adaptation, increasing the number of thinking steps across the round, but groups adapted much faster compared to individual players. Reflective thinking could have been facilitated by group deliberation increasing the thinking steps taken before the selection of a strategy.

In the third experiment of chapter 6 we tried to elucidate the role of different factors in strategic adaptation under conditions of strategic interdependence. Participants played 190 rounds of iterated repeated prisoner's dilemma against a computer that employed successively two kinds of probabilistic strategies. Results showed that: (1) Participants can perceive the complex strategic pattern of the opponent and can adapt their strategies when the opponents' strategies significantly change. (2) Performance of the participants has a bimodal distribution. (3) Good performance is clearly determined by the ability to adapt to the changing strategy of the opponent. (4) Beliefs about the opponent (computer/human) do not affect significantly the strategic behavior of the participants.

We showed that effects demonstrated under experimental settings persist in real-word situations, for example in educational settings. As described in chapter 5, strategic adaptation can be found in mathematical problem solving. Moreover, unwanted detrimental affects of abstract problems series can cause fixation and, as a consequence, pour performance in application of mathematical knowledge in practical problems.

Research results can have several applications in different domains of psychology, either in the assessment of cooperative behavior, or in several economic disciplines.

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