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ORIGINAL PAPER

Does exposure to alternative decision rules change gaze patterns and behavioral strategies in games?

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Abstract

We run an eye-tracking experiment to investigate whether players change their gaze patterns and choices after they experience alternative models of choice in one-shot games. In phase 1 and 3, participants play 2×2 matrix games with a human counterpart; in phase 2, they apply specific decision rules while playing with a computer with known behavior. We classify participants in types based on their gaze patterns in phase 1 and explore attentional shifts in phase 3, after players were exposed to the alternative decision rules. Results show that less sophisticated players, who focus mainly on their own payoffs, change their gaze patterns towards the evaluation of others' incentives in phase 3. This attentional shift predicts an increase in equilibrium responses in relevant classes of games. Conversely, cooperative players do not change their visual analysis. Our results shed new light on theories of bounded rationality and on theories of social preferences.

Keywords Game theory · Eye-tracking · Bounded rationality · Strategic sophistication · Social preferences

JEL Classification C72 · C51 · D84

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1 Introduction

Nash equilibrium is a prominent concept in game theory. However, extensive empirical evidence has shown systematic departures from standard equilibrium predictions in many different games (Camerer 2003). To account for the observed deviations, several theories tried to model choices by relaxing some of the assumptions of Nash equilibrium. On the one hand, theories such as level-k (Nagel 1995; Stahl and Wilson 1995; Crawford 2003; Crawford et al. 2013) and Cognitive Hierarchy (CH, Camerer et al. 2004; Chong et al. 2016) allowed more flexibility in players' beliefs, describing behavior in terms of hierarchical levels of strategic sophistication. The levels of strategic thinking are organized hierarchically starting from players who play randomly (level-0). The next level consists of level-1 players, who believe the counterparts to be level-0 and best respond to this belief; the following step involves level-2 players, who best respond to the belief that the counterparts are level-1 (in level-k theory) or a mixture between level-0 and level-1 (in cognitive hierarchy theory), and so on, moving up in the hierarchy. On the other hand, theories of social preferences (Rabin 1993; Fehr and Schmidt 1999; Bolton and Ockenfels 2000; Andreoni and Miller 2002; Fisman et al. 2007) relaxed the assumption of self-interest, assuming that agents have other-regarding preferences that modulate their utility function and, therefore, their choices.

In recent years, behavioral research has sought to describe the process underlying these different models of choice in game play. In particular, empirical works involving eye-tracking and mouse-tracking successfully characterized different types of players based on their payoff lookup patterns (Costa-Gomes et al. 2001; Hristova and Grinberg 2005; Brocas et al. 2014, 2018; Polonio et al. 2015; Devetag et al. 2016; Polonio and Coricelli 2019). Taken together, results show that sophisticated models of choice (level-2 or more) are associated with a specific pattern of information acquisition characterized by the exploration and evaluation of both own and others' incentives. However, less sophisticated players (level-1) disregard relevant pieces of information that are necessary to evaluate the incentives of the counterpart and to predict her move (Costa-Gomes et al. 2001; Polonio et al. 2015). Yet another type of player (cooperative) focuses on intra-cell comparisons between payoffs, framing the problem as a pure coordination game and disregarding dominant choices of the counterpart: this pattern of visual analysis lead to cooperative choices in line with models of social preferences (Devetag et al. 2016).

Although these works successfully describe the processes underlying out-of-equilibrium choices, they do not fully clarify the nature of the observed heterogeneity in gaze patterns. Specifically, we do not know whether level-1 players disregard others' incentives because they do believe that the other players do not have a preferred choice, or if players do not realize that they could play a more sophisticated strategy (Grosskopf and Nagel 2008; Goodie et al. 2012). At the same time, it is unclear if the emergence of strategies based on intra-cell comparisons is driven by the desire to maximize social well-being, or if it reflects a misrepresentation of the game structure and its interactive nature (Devetag and Warglien 2008).

To address these open questions, we run an eye-tracking experiment in which participants initially play different classes of one-shot 2×2 matrix games with a human counterpart (phase 1). In phase 2, they are asked to apply specific decision rules (level-1, level-2, and cooperative) playing the same games with a computer algorithm whose strategy is known, and are paid based on the actual compliance to the current rule. In phase 3, participants play the same games as in phase 1 with another human counterpart. We classify players as level-1, level-2, and cooperative types based on their lookup patterns in phase 1, and then explored changes in the visual analysis of the game matrix in phase 3, after participants have experienced the three models of choice. We are particularly interested in testing if level-1 and cooperative players change their type of visual analysis of the game matrix and their choices towards the one expected for more sophisticated types (i.e., level-2), after being exposed to the level-2 model of choice. We show that level-1 players shift their visual analysis towards the one characterizing level-2 players, devoting more attention to the counterpart's incentives. The attentional shift observed in level-1 players predicts an increase in the proportion of equilibrium responses in games in which the opponent has a dominant action. At the same time, cooperative players do not change their patterns of information acquisition, suggesting that their behavior is not driven by a misrepresentation of the game structure, but rather by other-regarding preferences. Taken together, these results offer new insights on theories of bounded rationality and social preferences.

2 Methods

2.1 Experimental design

100 students from University of Trento (Italy) participated in this study. At the beginning of each experimental phase, we instructed participants about the experimental procedure of the current phase and provided them with examples, control questions and training trials.[1] If participants failed one of the control questions, the instructions were repeated; if they failed the same control question a second time, they were dismissed.

In phase 1, each participant plays 48 2×2 one-shot matrix games with another randomly selected participant of the same pool.[2] All participants play in the role of row player and have to choose between row I and row II by pressing a button. Each game is played only once and no feedback is provided after each game. The order of the games is randomized across participants.

In phase 2, participants play with a computer that simulates the behavior of three different agents. Participants perform three different tasks that consist in the

[1] We provide the full translation of instructions and control questions in "Instructions and control questions" in the Electronic Supplementary Material (ESM).

[2] To pair each participant with a counterpart, the 48 games consist of 24 pairs of isomorphic games where row and column payoffs are identical but switched.

application of three different decision rules (level-1, level-2 and cooperative): in each of the three tasks, participants play the same 48 games of phase 1. All participants play each of the three tasks in random order. In the level-1 task, participants are told that the computer chooses randomly, and they are asked to provide a best response to the computer strategy by choosing the row with the highest average payoff. In the level-2 task, they are informed that the computer chooses the column with the highest average payoff, and they are asked to best respond to this prediction by choosing the row that maximizes the player's outcome within the computer's predicted action. In the cooperative task, participants are informed that the computer attempts to coordinate with the player to maximize the joint outcome, choosing the column containing the cell with the highest average payoff. Given the expected action of the computer, participants are asked to coordinate with the computer by choosing the row containing the cell that maximizes the joint outcome.

In phase 3, participants play again the same 48 games as in phase 1. They are informed that they will play with another participant from a separate experimental session involving the same games; they also know that their counterpart has not taken part in phase 1 and phase 2, and is not aware that the participants in this experiment have undertaken phase 1 and phase 2.[3]

At the end of the three sessions, players are paid based on their choices in the three phases. Specifically, in each of phases 1 and 3, one game is selected randomly and the participant's choice in each game is combined with the counterpart's choice in the same game (1–9 euros in each phase). In phase 2, participants are paid based on the rate of compliance to the current decision rule (maximum: 3.36 euros in each rule). The sum of the outcomes in the three phases constitutes the participants' final earnings (ranging from 2 to 28.08 euros).

In total, we excluded five participants due to non-compliance to the task instructions.[4]

2.2 Matrix games

We use four classes of 2×2 one-shot games (Figure A1, section A.1 of "Additional methods and results", ESM). 16 games are dominance solvable "self" games (DSS), in which only the participant (who chooses one of the rows) has a strictly dominant strategy. The other 16 games are dominance solvable "other" games (DSO), in which only the counterpart (who chooses one of the columns) has a strictly dominant strategy. DSS and DSO games have a unique Nash equilibrium. DSO games differ from DSS games because participants need two steps of iterated elimination of dominated strategies to detect the Nash equilibrium. Conversely, in DSS games,

[3] In phase 3, participants are paired with a counterpart who has played the same 48 games in a separate experimental session involving a single round of game play, without any preceding task involving decision rules.

[4] Two participants failed for two consecutive times at least one of the control questions of the experiment. Three participants misapplied the level-2 decision rule in the level-2 task (phase 2), exhibiting visual analysis and choices that were inconsistent with the decision rule.

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participants need only one step of iterated elimination of dominant strategies over their own actions. Games within each of the two classes vary in terms of magnitude of payoffs and relations between payoffs, but always maintain the described structure of dominance between actions.

We also use 16 games with multiple equilibria. Eight of these games are Stag-Hunt (SH), a coordination game with two equilibria (one of which is Pareto efficient) in which both players can choose between a safe/low return equilibrium and a risky/high return one. The other eight games are games of chicken (GOC), an anti-coordination game with two equilibria in which it is mutually beneficial for players to play different strategies.

2.3 Eye movement data analysis

We describe the eye-tracking procedure in detail in section A.1 of "Additional methods and results" in the ESM.

We characterize lookup patterns by considering transitions, which consist in eye movements from one payoff to the next. In particular, we focus on those transitions that are important for extracting relevant information about the structure of the game (Polonio et al. 2015; Devetag et al. 2016). We divide transitions into three major types:

1. Own transitions: transitions between the player's own payoffs.
2. Other's transitions: transitions between the counterpart's payoffs.
3. Intra-cell transitions: transitions between the payoffs of the two players, within the same cell.

Each type of transition expresses the encoding of specific pieces of information within the payoff matrix. We analyze the patterns of analysis by pooling data from different types of games, since it has been already shown that patterns of information acquisition are stable across classes of games. A high proportion of own transitions has been shown to predict the implementation of the level-1 (L1) strategy, which focuses on the best response to the belief that the counterpart chooses each action with equal probability. A high proportion of other's transitions are associated with the implementation of the level-2 (L2) model of choice, which requires the evaluation of the other's incentives to predict the counterpart's move. Intra-cell comparisons are used by cooperative players to detect the cell that maximizes the joint outcome.

Following Jiang et al. (2016), we classify our participants in types based on the comparison between their analysis in phase 1 and the one used to apply the three decision rules in phase 2. In particular, for each participant, we take proportions of own, other, and intra-cell transitions in phase 1 and we calculate their Euclidean distance from the participant's proportions of transitions in each of the three

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Table 1 Average distances from the patterns of visual analysis during the application of decision rules in phase 2 (L1 dist., L2 dist., Coop dist.), divided by phase (1 and 3) and groups (level-1, level-2 and cooperative)

Group (phase 1)	*n*	Phase 1			Phase 3		
		L1 dist.	L2 dist.	Coop dist.	L1 dist.	L2 dist.	Coop dist.
Level-1	19	0.14 (0.09)	0.39 (0.12)	0.46 (0.13)	0.27 (0.20)	0.28 (0.18)	0.40 (0.17)
Level-2	35	0.37 (0.08)	0.17 (0.05)	0.31 (0.07)	0.39 (0.10)	0.17 (0.09)	0.31 (0.12)
Cooperative	41	0.45 (0.10)	0.29 (0.08)	0.13 (0.08)	0.42 (0.16)	0.30 (0.12)	0.19 (0.16)

Groups are defined based on the gaze data in phase 1. Standard deviations in brackets

tasks of phase 2.[5] This gives us individual measures of distance from L1, L2, and cooperative visual analyses (L1, L2 and cooperative distances). Participants are then assigned to types (L1, L2 or cooperative) based on the lowest between these three distances.

Once we have classified participants in types based on gaze data in phase 1, we investigate whether their attentional patterns change in phase 3. In particular, we test if L1 and cooperative players, in phase 3, switch towards the type of visual analysis typical of L2 play. To address this hypothesis, we focus on changes in L2 distance from phase 1 to phase 3: the decrease in L2 distance for L1 and cooperative participants would indicate the increase in the sophistication of their gaze patterns.

3 Results

3.1 Gaze patterns in phase 1 and 3

Results of the classification of participants into L1, L2, and cooperative types based on the gaze patterns in phase 1 are reported in Table 1. The average distances in phase 1 obviously reflect the classification in types: the L1 group ($n=19$) is best characterized by the shortest distance to the L1 strategy, the L2 group ($n=35$) by the shortest distance to the L2 strategy, and the cooperative group ($n=41$) by the shortest distance to the cooperative strategy. Looking at the distances in phase 3, we can already observe a notable change in the L1 group, whose L1 and L2 distances are now very close to each other. Conversely, L2 and cooperative groups seem to maintain similar distances.

We analyze these effects by running a random effects linear regression with errors clustered by subject (robust standard errors) using L2 distance as a dependent variable and dummies for group and phase as independent variables (Table 2). Phase 1 and L2 group serve as a baseline. Results show that L1 players decrease their L2 distance significantly more than L2 players, while the effect is absent in the cooperative

[5] In the characterization of gaze patterns in phase 2, we considered only trials in which the current rule was correctly applied. In general, participants achieved a very high average accuracy in every task (i.e., rule) of phase 2 (level-1: $M=0.98$; level-2: $M=0.96$; cooperative: $M=0.97$).

Table 2 Random effects linear regression with errors clustered by subject

L2 distance	B	Robust SE	Z	p	95% CI	
Phase 3 (L2 group)	−0.00	0.12	−0.04	0.968	−0.23	0.22
L1 group (phase 1)	1.72	0.23	7.51	<0.001	1.27	2.17
Cooperative group (phase 1)	0.99	0.12	8.02	<0.001	0.74	1.23
Phase 3×L1 group	−0.84	0.37	−2.27	0.023	−1.56	−0.11
Phase 3×cooperative group	0.03	0.16	0.20	0.839	−0.28	0.34
Intercept	−0.69	0.07	−10.34	<0.001	−0.82	−0.56
n. obs	190					
n. independent obs	95					

Standard errors are robust. L2 distance is the dependent variable and phase, group and their interactions are the independent variables. Baseline: L2 group in phase 1

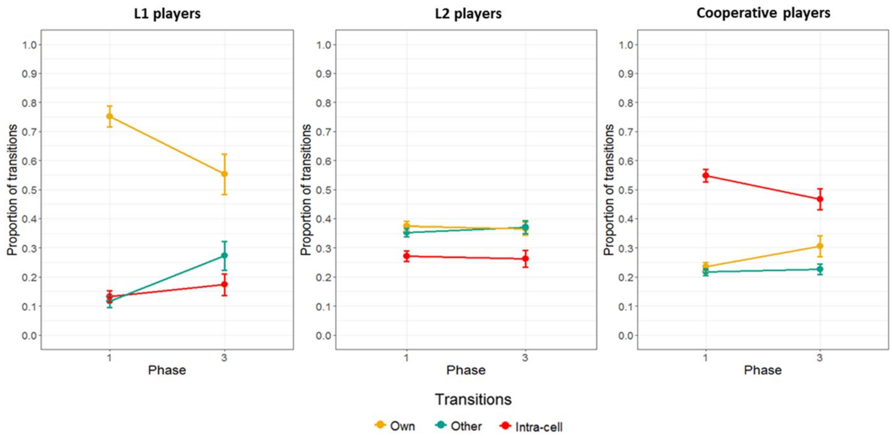

Fig. 1 Proportion of own, other and intra-cell transitions in phase 1 and phase 3 for the three player types

group (interaction effects, Table 2: Phase 3×L1 group, $B=-0.84$, $p=0.023$; phase 3×cooperative group, $B=0.03$, $p=0.839$). Testing linear combination of coefficients, we can observe that only the L1 group shows a significant decrease in the L2 distance from phase 1 to phase 3 ($B=-0.84$, $p=0.016$), while there is no effect of phase in both L2 ($B=-0.00$, $p=0.968$) and cooperative ($B=0.03$, $p=0.800$) groups.

To test these effects in more detail, we analyze between-phase changes in the proportion of relevant transitions (Fig. 1).

Specifically, we run three random effects linear regressions with errors clustered by subject (robust standard errors) using as dependent variables the proportions of own, other's and intra-cell transitions, and dummies for group and phase as independent variables (Table A1, section A.2 of "Additional methods and results", ESM). We use phase 1 and L2 group as a baseline. Consistently with the effect of switch towards the L2 visual analysis (Table 2), L1 players increase their proportion of other's transitions (linear combination of coefficients, $B = 1.08$, $p = 0.004$) and decrease their proportion of own transitions ($B = -0.77$, $p = 0.031$). These effects are stronger in L1 players than in L2 players (interaction effects, other: $B = 0.85$, $p = 0.031$; own: $B = -0.80$, $p = 0.033$), who in turn do not show any effect of phase on transition proportions (linear combination of coefficients, own: $B = 0.03$, $p = 0.793$; other: $B = 0.22$, $p = 0.076$; intra-cell: $B = 0.02$, $p = 0.840$). The attentional shift of L1 players indicates that the exposure to a more sophisticated rule may increase the focus on the evaluation of the other's incentives to form beliefs about the counterpart's action.

Cooperative players, in phase 3, exhibit a significant increase in own transitions ($B = 0.32$, $p = 0.026$), but no phase difference in the proportion of other's transitions ($B = 0.13$, $p = 0.237$).[6] The absence of an effect on other's transitions in cooperative players is important to explain their stability in terms of L2 distance across phases. Altogether, our results suggest that cooperative players did not move towards a more sophisticated visual analysis (L2) in phase 3.

3.2 Choices in phase 1 and phase 3

In this section, we test whether the switch in visual analysis (i.e., decrease in L2 distance) from phase 1 to phase 3 in L1 players is directly associated with a change in players' choices. We consider the proportion of equilibrium responses in DSS and DSO games and the proportion of risk-dominant equilibrium choices in both SH games and GOC. We run regressions with the increase in the proportion of equilibrium response (phase 3–phase 1) in each of the four classes of games as dependent variables, and the decrease in L2 distance (phase 1–phase 3) as independent variable (Table A2, section A.2 of "Additional methods and results", ESM). Results show that the decrease in L2 distance predicts the increase in the proportion of equilibrium responses in DSO games in L1 players ($B = 0.61$, $p < 0.001$). This effect leads to a modest average increase (16%) in equilibrium responses in DSO games for the L1 group ($B = 0.64$, $p = 0.052$).[7] DSO games are crucial since an equilibrium can be found only by predicting the counterpart's move and best responding to this expectation. We do not find any other significant effect of phase on the proportion of equilibrium or risk-dominant choices across groups and classes of games (Table A3, section A.2 of "Additional methods and results", ESM). In Table 3, we report the proportion of equilibrium responses in each class of game in phase 1 and phase 3.

[6] The modest shifts in gaze patterns observed in cooperative players were not statistically different from the ones of L2 players (Table A1 (interaction effects), section A.2 of "Additional methods and results", ESM).

[7] Random effects linear regression with errors clustered by subject (robust errors). The proportion of equilibrium responses is the dependent variable, dummies for group and phase as independent variables.

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Table 3 Proportion of equilibrium responses (risk dominant equilibrium for SH and GOC games) organized by group, phase and game

Group (phase 1)	*n*	Proportion of equilibrium responses							
		Phase 1				Phase 3			
		DSS	DSO	SH	GOC	DSS	DSO	SH	GOC
Level-1	19	0.85 (0.16)	0.31 (0.23)	0.77 (0.24)	0.68 (0.26)	0.85 (0.14)	0.47 (0.31)	0.73 (0.30)	0.73 (0.33)
Level-2	35	0.87 (0.13)	0.69 (0.21)	0.69 (0.30)	0.64 (0.27)	0.90 (0.15)	0.74 (0.27)	0.69 (0.38)	0.64 (0.31)
Cooperative	41	0.66 (0.21)	0.57 (0.15)	0.38 (0.31)	0.74 (0.31)	0.73 (0.23)	0.54 (0.22)	0.43 (0.41)	0.77 (0.33)

Standard deviations in parentheses

4 Conclusion

In an eye-tracking experiment, we investigate if unsophisticated types of players change their patterns of information acquisition and choices after they experience alternative decision rules. Results show that the visual analysis of level-1 players shifts towards the one predicted by the level-2 strategy after the exposure to alternative decision rules, including level-2 play. This effect is driven by an increase in the proportion of other's payoff transitions, suggesting that the attentional shift is directed towards the evaluation of the incentives of the counterpart to form beliefs about her preferred action. These findings indicate that level-1 players, if exposed to more sophisticated strategies, do realize that they should consider more thoughtfully the incentives of the counterpart. Our results are in line with the hypothesis that unsophisticated behavior is associated with a non-exhaustive representation of the game structure (Devetag and Warglien 2008) or the action space of the players involved in the interaction (Verbrugge et al. 2018). Moreover, the observed attentional shift predicts a selective increase in the rate of equilibrium responses in games in which the counterpart has a dominant action, suggesting that the other-oriented change in gaze patterns has an impact on choices in relevant games. These results are consistent with recent findings (Verbrugge et al. 2018) showing that players can increase their level of strategic thinking after step-by-step training and instructions about the existence of different levels of reasoning in games. Nevertheless, we acknowledge that the average shift in choices for L1 players is rather modest, which can be explained in several ways. On the one hand, it is possible that the simple exposure to alternative models of choice, without any information about their efficacy, is not sufficient for a robust increase in strategic sophistication. On the other hand, we can hypothesize that the increase in the attention towards other's incentives does not necessarily translate into a comparable increase in strategic thinking. This interpretation is in line with recent results (Polonio and Coricelli 2019) showing that level-1 players choose the level-1 action even if they believe that their counterpart has a preferred action.

Moreover, our results show that cooperative players do not change their patterns of visual analysis and continue to focus on intra-cell comparisons and play cooperatively after exposure to alternative rules. These results suggest that the visual analysis and behavioral strategy of these players are motivated by the desire to achieve the social optimum, even if they are aware of the steps of strategic reasoning that are necessary for maximizing their personal payoff. This indicates that the behavior of cooperative players is driven by other-regarding preferences, as suggested by recent studies (Polonio et al. 2015; Devetag et al. 2016), highlighting how theories of social preferences can capture behavior of a substantial segment of players in one-shot games. Altogether, our results provide novel evidence about the cognitive drivers and the stability of attentional patterns and behavioral strategies in games, and shed new light on theories of bounded rationality and on theories of social preferences.

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