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Gaze patterns disclose the link between cognitive reflection and sophistication in strategic interaction

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Abstract

In social contexts, we refer to strategic sophistication as the ability to adapt our own behavior based on the possible actions of others. In the current study, we explore the role of other-oriented attention and cognitive reflection in explaining heterogeneity in strategic sophistication. In two eye-tracking experiments, we registered eye movements of participants while playing matrix games of increasing relational complexity (2x2 and 3x3 matrices), and we analyzed individual gaze patterns to reveal the ongoing mechanisms of integration of own and others' incentives in the current game representation. Moreover, participants completed the Cognitive Reflection Test (CRT), in addition to alternative measures of cognitive ability. In both classes of games, higher cognitive reflection levels specifically predict the ability to incorporate the counterpart's incentives in the current model of the game, as well as higher levels of strategic sophistication. Conversely, players exhibiting low cognitive reflection tend to pay less attention to relevant transitions between the counterpart's payoffs, and such incomplete visual analysis leads to out-of-equilibrium choices. Gaze patterns appear to completely mediate the relationship between cognitive reflection and strategic choices. Our results shed new light on the cognitive factors driving heterogeneity in strategic thinking and on theories of bounded rationality.

Keywords: strategic sophistication, cognitive reflection, gaze patterns, game representation, bounded rationality

1 Introduction

In our everyday experience, we often face situations in which the outcome of our decisions is influenced by the decisions of other agents. In this context, it is important to understand others' goals and intentions to predict their actions, an ability that is referred to as "mentalizing" or "Theory of Mind" (ToM, Premack & Woodruff, 1978). Nonetheless, accumulating experimental evidence has shown that agents are often non-strategic. They also deviate from the Nash equilibrium strategies (Grosskopf & Nagel, 2008), which postulate perfect self-interested rationality of players that have consistent beliefs about others' behavior and select the best action given their expectations (Mailath, 1998).

In order to account for the heterogeneity observed in interactive games, behavioral models of strategic thinking such as Level-K (Crawford, 2003; Crawford et al., 2013; Nagel, 1995; Stahl & Wilson, 1995) and Cognitive Hierarchy (CH, Camerer et al, 2004; Chong et al., 2016; Ho et al., 1998) allowed more flexibility in players' beliefs, modelling behavior in terms of hierarchical levels of strategic thinking (Nagel, 1995). These models describe the strategy space of players building a hierarchical structure that predicts, at the bottom, players who play randomly (level-0). The second step in the hierarchy corresponds to level-1 players, who best respond to the belief that the counterparts are level-0; the following step predicts level-2 players, who best respond to the belief that the opponents are level-1 (in Level-k theory) or a mixture between level-0 and level-1 (in Cognitive Hierarchy theory), and so on, increasing the number of steps of strategic thinking. Behavioral models of strategic thinking therefore assume that each player has to estimate the level of rationality of the other agents involved in the interaction (Pantelis & Kennedy, 2017).

These models offer an elegant description of the heterogeneity observed in interactive decisions, but do not provide a cognitive explanation of the factors modulating this variability. For instance, it is not clear if agents applying few steps of strategic thinking believe that the other players are boundedly rational and therefore best-respond to this belief, or whether they are boundedly rational themselves (Goodie et al., 2012; Grosskopf and Nagel, 2008). In this regard, one of the crucial components of mentalizing concerns the constructions of an exhaustive and correct mental model of the decision space of the counterpart, in order to predict her next action and therefore best-respond to it (Hedden & Zhang,

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2002). However, some experimental evidence suggests that deviations from normative responses in strategic interaction depend on poor game representations. These misrepresentations may arise from the generation of a miserly model of the opponent's incentives and potential moves (Verbrugge et al., 2018), the relational structure of the game payoffs (Devetag & Warglien, 2008), or the relationships between own and other's potential actions and outcomes (Rydval et al., 2009). In other words, if agents do not incorporate specific chunks of information (e.g., the incentives of the opponent) in their model of the strategic environment, or if they integrate them inaccurately with other available information, they would be unlikely to achieve optimal game solutions (Kreps, 1990).

1.1 Gaze patterns and game representation

Given the importance of mechanisms of information encoding and representation in strategic interaction, process-tracing research has recently explored processes of game (mis)representation by observing the patterns of information acquisition characterizing game playing. Costa-Gomes et al. (2001) used mouse-tracking to disclose the processes of information search in normal form games, identifying nine strategic types of player. A relevant proportion of these participants exhibited choices and information acquisition patterns consistent with predictions of level-k models. Hristova & Grinberg (2005) showed that cooperative behavior in a Prisoner Dilemma (PD) game was linked to the distribution of attention between payoffs matrix and opponent's moves. In two mouse-tracking experiments, Brocas et al. (2014, 2018) showed that failure to look at required pieces of information predicts out-of-equilibrium play in private information games (Brocas et al., 2014) and sequential and simultaneous dominance solvable games of complete information (Brocas et al., 2018).

Polonio et al. (2015) used eye-tracking to cluster participants in types of player depending on their frequency distribution of classes of transitions connecting matrix payoffs. The cluster analysis returned three categories of player: 1) players focusing on their own payoffs, 2) players mostly performing intra-cell comparisons, and 3) players with distributed attention. The two former types did not perform the payoff comparisons necessary for individuating the equilibrium strategy. In particular, players focusing on own payoffs did not incorporate the possible actions of the opponent in their decision model and chose in accordance to the expected strategy of a Level-1 (L1) player, who responds to the belief that the opponent does not have a preferred action. Players that focused on intra-cell comparisons did considered opponents' payoffs, but framed the problem as a pure coordination game, disregarding dominant choices of the opponent. In contrast, both visual analysis and choices of the latter type of player were consistent with the expected behavior of a Level-2 (L2) player, who assumes that the counterpart is a L1 player and, given such belief, best responds to the expected counterpart's action.[1] Altogether, these results suggest that some players systematically misrepresent and simplify interactive problems by disregarding those payoff comparisons that are necessary for mentalizing and strategic thinking. Importantly, game misrepresentation leads to deviation from game-theoretical equilibrium choices, supporting the idea that the internal representation of the game structure is a crucial component of the interactive decision process.

1.2 Cognitive abilities, game representation and strategic sophistication

Recent experimental research has asked whether specific cognitive factors could explain individual differences in strategic sophistication. Several studies have indeed shown correlations between behavior in games and different measures of cognitive ability and executive functions (Burks et al., 2009; Burnham et al., 2009; Gill & Prowse, 2016). The Cognitive Reflection Test (CRT, Frederick, 2005) has been particularly successful in explaining choices in several interactive games, including the Beauty Contest Game (Carpenter et al., 2013; Fehr & Huck 2016; Brañas-Garza et al., 2012), the Hit 15 game (Carpenter et al., 2013), bank-run games (Kiss et al., 2016) and matrix games (Georganas et al., 2015; Hanaki et al. 2016). The CRT assesses individual differences in cognitive style: particularly the tendency to rely more on either reflective or intuitive cognitive processes (Alós-Ferrer et al., 2016; Baron et al., 2014; Mata et al., 2013; Szaszi et al., 2017). High cognitive reflection levels have also been linked to the tendency to use more thorough search processes (Cokely & Kelley, 2009; Cokely et al., 2009) and to the ability to accurately process and represent task-relevant information (Mata et al., 2014; Sirota et al., 2014). Moreover, the CRT is related to analytical thinking (Hoppe & Kusterer, 2011), behavioral biases (Oechssler et al., 2009), probabilistic reasoning (Koehler & James, 2010; Liberali et al., 2012) and rule abstraction (Don et al., 2016). Conversely, a low cognitive reflection level is associated with miserly information processing (Toplak et al., 2014). Taken together, these findings indicate involvement of cognitive reflection in the processes of information encoding, integration and representation underlying judgment and decision making tasks. In the context of strategic interaction, we therefore hypothesize that cognitive reflection may specifically modulate mechanisms of information processing underlying game representation, which in turn predict the level of sophistication in strategic interaction.

To test this hypothesis, we conducted two eye-tracking experiments involving matrix games between two players. Matrix games consist in a set of incentives (i.e., payoffs) and

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[1] Concerning the relationship between Level-k models and gaze data, see also Stewart et al. (2016) who showed inconsistencies between patterns of information acquisition and Level-k or Cognitive Hierarchy models.

an action set for each player: the combination of players' decisions therefore determines their respective outcomes. Games were one-shot, meaning that participants did not receive any feedback about the action of the opponent and the game outcome after their choice in each game. In Experiment 1 participants played 2x2 matrix games, while in Experiment 2 we increased game complexity introducing 3x3 matrices. Experiment 2 was designed to explore the generalizability of the effect of cognitive reflection on game play, and investigate whether game complexity could affect the hypothesized relationship between cognitive reflection and game representation. We analyzed participants' gaze patterns to reveal the type of game representation that they were building, and administered the Cognitive Reflection Test (CRT) to obtain individual measures of cognitive reflection. Additional measures of fluid intelligence and working memory abilities were collected to investigate the cognitive specificity of the role of cognitive reflection in modulating game representation processes and strategic sophistication. Both experiments are based on the same analysis structure. First, we tested whether cognitive reflection predicts strategic choices and hierarchical levels of strategic thinking in games. Second, we explored the relationship between game representation and strategic behavior by looking for gaze patterns of information acquisition that could predict the level of sophistication in strategic choices. Third, we explored the relationship between patterns of information acquisition and cognitive reflection. Finally, we tested whether gaze patterns mediate the relationship between cognitive reflection and choices.

2 Experiment 1

2.1 Methods

2.1.1 Participants and procedure

Participants were 48 students from the University of Trento, Italy (34 females, mean age 23.02, SD 2.84). The study was approved by the local ethics committee and all participants gave informed consent. Participants performed thirty-two 2x2 one-shot matrix games. Before playing the games, they were instructed on the procedure and were provided with examples and training trials (4 games). Moreover, we administered control questions to participants to verify that they have fully understood task and procedure of payment. If participants failed to answer control questions, instructions were repeated (detailed instructions and control questionnaires are reported in section C.1 of the Appendices). All participants played in the role of row player[2] and were instructed to choose between row I and row II by key-press. The order of games was randomized for each participant. Each game was played only once and no feedback was provided at the end of games. Trials were preceded by a fixation-point positioned in one of four possible locations outside the matrix. At the end of the experimental session, three games were randomly selected and the player's choice in each game was paired with the choice of another player in that very same game. Participants received the sum of the outcomes of the three games in euros (from 3 to 27 euros).

In addition to 2x2 games, all participants took the Cognitive Reflection Test (CRT, Frederick, 2005) and additional cognitive tests of fluid intelligence and working memory in order to test the specificity of the effect of cognitive reflection. Fluid intelligence was assessed using a time-limited version (Schmittmann, 2006) of the Raven Advanced Progressive Matrices Test (APM; Raven et al., 1998). Working memory measures included digit span forward and backward (Wechsler, 2008) and the n-back task (Kirchner et al., 1958). Forward digit span measures abilities in simple short-term maintenance and recall of digits, while the backward span requires an additional component of mental manipulation of elements (Baddeley, 1996; Monaco et al., 2013). The n-back task assesses the ability to actively maintain and update information in working memory, and targets mechanisms linked to executive control such as inhibition and interference resolution (Kane et al., 2007). We report the exact procedure of these control cognitive tests in section A.1 of the Appendices.

2.1.2 2x2 Matrix games

In the current work, we used games characterized by a unique game theoretical optimal solution, which is commonly described using the concept of Nash equilibrium (Nash, 1950). Nash equilibrium is a game solution in which none of the players has a self-interested incentive to deviate from its own strategy after considering the counterpart's choice. In Experiment 1, we used a particular class of game called *dominance-solvable*. These games contain an option which is better than another one for a player, independently of the action the counterpart will take. We refer to this option as a *dominant strategy*.[3] In Experiment 1, we used two classes of dominance-solvable games characterized by different equilibrium structures, creating sixteen 2x2 games for each class (for a full list of game matrices, see Figure A1 in section A.1, Appendices). The two classes of games (Figure 1) were: (1) dominance solvable "self" games (DSS), in which only the participant had a strictly dominant strategy; (2) dominance solvable "other" games (DSO), in which only the opponent had a strictly dominant strategy.

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[2] In order to pair each participant with an opponent, the 32 games consisted of 16 pairs of isomorphic games in which row and column payoffs were identical but switched; in such a way, it was possible to match the choices of two row players as they have played in two different roles.

[3] Since dominant strategies in our games dominate every alternative option of one of the players, they are additionally referred to as strictly dominant.

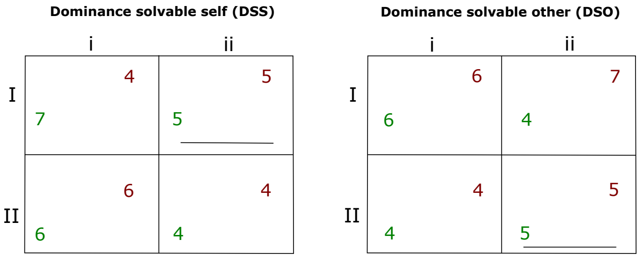

FIGURE 1: Examples of dominance solvable self (DSS) and dominance solvable other (DSO) games. All participants played in the role of row players. In this example, we report two isomorphic games in which row and column payoffs are identical but switched. The line in one of the cells of each matrix signals the equilibrium solution of the game. Taking the perspective of a row player, the DSS game shown in the current figure contains a strictly dominant strategy (option I): in fact, it returns a higher payoff than option II independently of the column player's choice. Given this dominant strategy, the column player optimizes its payoff by choosing option ii. In the DSO game, the column player has a strictly dominant strategy (option ii) and the row player would best respond by choosing option II. The black lines represent Nash equilibria.

Both types of dominance-solvable game had a unique pure strategy Nash equilibrium that always coincide with level-2 play in hierarchical models of strategic thinking. DSO games differ from DSS games because the equilibrium solution requires two steps of iterated elimination of dominant strategies that include the evaluation of the counterpart's incentives (first, individuating the strict dominance of the counterpart; second, choosing the best response given the opponent's dominant choice). In contrast, the equilibrium solution in DSS games needs only one step of iterated elimination of dominant strategies between participant's own possible choices and therefore does not even require the evaluation of the counterpart's incentives. For this reason, only DSO games require strategic sophistication for the equilibrium strategy. Games within a class could vary in terms of magnitude of payoffs and location of the payoffs in the matrix, but maintained the described relations of dominance between choices.

2.1.3 Eye-tracking procedure

While playing matrix games, participants were seated in a chair with a soft head restraint to ensure a viewing distance of 55 cm. from a monitor with 1920 x 1080 resolution. Presentation of the stimuli was performed using a custom-made program implemented using Matlab Psychtoolbox. Eye movements were monitored and recorded using a tower mounted Eyelink 2000 system (SR. Research Ontario Canada) with a sampling rate of 2000 Hz. In matrix games, we used a calibration with 13 points: points were placed in the exact locations of payoffs, at the center of the matrix and in the four possible locations of the fixation cross. After the calibration phase, a validation phase was performed to make sure that the calibration was accurate. The position of points in the validation phase was identical to the one in the calibration phase. Re-calibrations and re-validation were performed if these had been unsuccessful. Before the beginning of each trial, a drift correction was performed in order to control that participants look at the current fixation location; stimuli were presented after the fixation point was fixated for 300 milliseconds. Stimuli were placed at an optimal distance between each other in order to precisely distinguish goal-directed saccades and fixations.

2.1.4 Gaze data analysis

Following the eye-tracking analysis performed by Polonio and colleagues (2015), we defined eight regions of interest (ROIs), centered on the matrix payoffs. All the ROIs had a circular shape with a size of 36000 pixels. The ROIs covered only 23% of the game matrix area and did not overlap. All the fixations that did not fall within any ROIs were discarded. However, although a consistent portion of the matrix was not included in any of the ROIs, the large majority of fixations (87.4%) were located inside the ROIs.

We focused on two main types of gaze data analysis: fixation and transition analysis.[4]

On the one hand, fixation analysis can reveal with extremely high accuracy which piece of information is being processed in a specific time unit (De Neys & Osman, 2013). In the current experiment, fixation analysis was useful to explore, for each player, the distribution of attention between own and other's payoffs, revealing in what measure players incorporate others' incentives in their model of the interactive problem.

On the other hand, transitions express eye movements (i.e., saccades) from one payoff (AOI) to the next. Saccades are generally thought to reflect a direct an obligatory consequence of overt attentional shifts (e.g., Deubel & Schneider, 1996; He & Kowler, 1992; Hoffman & Subramaniam, 1995). These top-down attentional shifts occur when the processing of the attended item reaches some critical level, triggering the visual system to prepare a motor program enabling a saccade towards the next target (De Neys & Osman, 2013). In the context of matrix games, transitions specifically provide information about the pieces of information that participants were comparing and therefore incorporating in their model of the interactive problem. In particular, we considered those transitions that were useful to extract information about the structure of the payoff matrix and build a representation of

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[4] A fixation was defined as an interval in which gaze was focused within 1° of visual angle for at least 100 ms (Manor and Gordon, 2003).

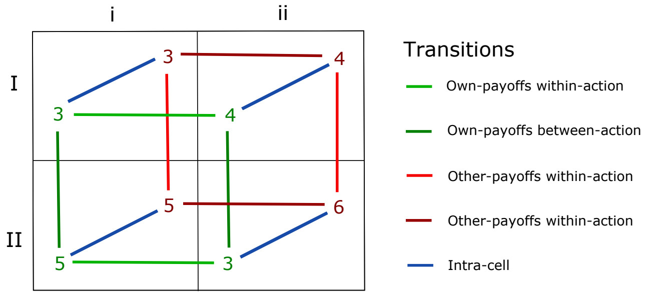

FIGURE 2: Relevant types of transitions between payoffs. The direction of the transition from one payoff to the other is irrelevant for classification.

the current game.[5] In order to explore the type of visual analysis performed by participants, transitions were divided in five major types (Figure 2), following the classification of Devetag and colleagues (2016):

1) own-payoffs within-action transitions: transitions between player's own payoffs within a single row (necessary to identify the action with the highest average payoff).

2) own-payoffs between-action transitions: transitions between player's own payoffs within a single column (necessary to identify the presence of own dominant choices).

3) other-payoffs within-action transitions: transitions between the counterpart's payoffs within a single column (necessary to identify the counterpart's choice with the highest average payoff).

4) other-payoffs between-action transitions: transitions between the counterpart's payoffs within a single row (necessary to identify the presence of counterpart's dominant choices).

5) intra-cell transitions: transitions between the payoffs of the two players, within the same cell (necessary to compare the two players' payoffs given a specific combination of choices).

2.2 Hypotheses

In Experiment 1, we asked whether cognitive reflection modulates attentional mechanisms underlying representation building, as expressed by gaze patterns, and individual levels of strategic sophistication in 2x2 games. Behaviorally, we expect high CRT players to show higher levels of strategic thinking (i.e., level-2) in the framework of the Cognitive Hierarchy model. High CRT players should therefore play more often the equilibrium strategy, which is optimal (in our 2x2 games) in response to a typical population whose strategic level ranges between level-1 and level-2 (Camerer et al., 2004). This behavioral effect should emerge in DSO games, which require strategic sophistication and can reveal choice differences between players characterized by different levels of strategic thinking (e.g. level-1 and level-2).

At the same time, we expect the CRT score to predict sophistication in the visual analysis of the game matrix. We do not predict differences between DSS and DSO games, since previous results (Polonio et al., 2015) have shown that the visual analysis of game matrices is consistent across classes of games: this hypothesis is in line with the idea that the visual analysis of the game matrix is controlled by a top-down modulation of attention. We hypothesize high CRT players to exhibit the typical gaze patterns of more sophisticated types of players (Costa-Gomes et al., 2001; Devetag et al., 2016; Polonio et al., 2015; Polonio & Coricelli, 2019). In particular, high CRT players should make a higher proportion of other-payoff within-action transitions, suggesting the attempt to form precise (non-diffuse) beliefs about the expected action of the counterpart, and to identify the counterpart's action with the highest average payoff. This is consistent with the expected behavior of a level-2 player that aims to best respond to the predicted action of a level-1 player (Bhatt & Camerer, 2005; Costa-Gomes et al., 2001). On the contrary, we expect low CRT players to rely on a less exhaustive game representation that does not incorporate the evaluation of other's incentives to predict her move and therefore implement recursive strategic thinking. Finally, we hypothesize that the relationship between CRT score and strategic choices is mediated by the level of sophistication of the visual analysis of the payoff matrix.

2.3 Results

2.3.1 Behavioral results

As expected, the proportion of equilibrium responses in DSO games is significantly lower than in DSS games (DSS: M = 0.85, SD = 0.17; DSO: M = 0.56, SD = 0.22, Wilcoxon matched-pairs signed-rank test, z = 5.21, effect size (r) = 0.75, $p < .001$). These results confirm that heterogeneity in strategic sophistication emerges in those games in which taking into account the possible incentives of others is fundamental.

2.3.2 Cognitive reflection and strategic sophistication

First, we investigated the relationship between cognitive reflection and the proportion of Nash equilibrium choices in DSO games, where strategic sophistication is required to

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[5] Other types of transitions that are excluded from this classification (e.g. transitions connecting own and other's payoffs across cells) do not allow to extract relevant information about the payoff structure (see for instance Devetag et al., 2016). We acknowledge that the proportion of these type of "non-useful" transitions is rather high (48.09%), since they are geometrically necessary to perform the scan paths necessary to extract relevant information about the game structure. However, the implementation of these types of transitions is not linked to the proportion of equilibrium responses neither in DSS (Spearman's rank correlation, r = −0.08, p = 0.59) nor in DSO (r = −0.07, p = 0.65) games, confirming that they do not constitute relevant payoff-comparisons allowing the extraction relevant information for game resolution.

TABLE 1: For each CRT group, we report the parameter τ (CH), which expresses the average group level of strategic thinking in the Cognitive Hierarchy (CH) model, and the average proportion of equilibrium responses in DSS and DSO games (standard deviations in brackets).

			Proportion of equilibrium responses	
CRT score	N	τ (CH)	DSS	DSO
0	14	1	0.78 (0.19)	0.48 (0.18)
1	10	1.6	0.88 (0.13)	0.58 (0.18)
2	14	1.32	0.88 (0.14)	0.50 (0.23)
3	10	2.26	0.86 (0.18)	0.74 (0.21)

find the optimal solution. In order to evaluate the specificity of the effect of cognitive reflection on strategic choices, we ran a stepwise backward regression (Draper & Smith, 1998; Efroymson, 1960; Hocking, 1976) on the average proportion of equilibrium responses in DSO games including the CRT score, the Raven score and the three measures of working memory as independent variables.[6] Results indicate that the model that best predicts the proportion of equilibrium choices included only the CRT score (R^2 = .11, F (1, 46) = 5.59, B = 0.33, p = .022), while we did not find any effect of fluid intelligence or working memory on strategic behavior (Variables excluded from the model: Raven score, digit span forward, digit span backward, n-back score: p > .05).[7] As expected, cognitive reflection does not affect the proportion of equilibrium responses in DSS games (B = 0.06, p = .709), where strategic sophistication is not needed.[8] These results highlight the crucial role of cognitive reflection in strategic thinking.

Then we tested whether the CRT score was associated with the level of strategic thinking predicted by the Cognitive Hierarchy (CH) model, which describes interactive behavior by a hierarchy of decision rules differing in the number (k) of steps of thinking used. In CH, the frequency distribution f (k) of steps of players is assumed to be Poisson, and its mean and variance is described by a single parameter τ. The higher the τ of a population, the higher its level of strategic sophistication. Therefore, we estimated τ for each of our CRT groups, expecting the value of τ to increase along with the CRT level. As expected, the higher the CRT level, the higher the free parameter τ (CRT = 0, τ = 1; CRT = 1, τ = 1.6; CRT = 2, τ = 1.32; CRT = 3, τ = 2.26). Interestingly, players with CRT = 0 exhibit a τ parameter which expresses the expected behavior of a L1 player, while players with CRT = 3 have a τ parameter reflecting the strategy of a L2 player. Players with CRT = 1 and CRT = 2 lie in between these two levels of strategic behavior. Results of the CH model estimation show that cognitive reflection is indeed associated with level of strategic thinking in our 2x2 games. In Table 1, for each CRT level, we report the group level of strategic thinking (τ) and the average proportion of equilibrium responses. Figure 3 shows boxplots of average proportion of equilibrium responses for each CRT level in DSS and DSO games.

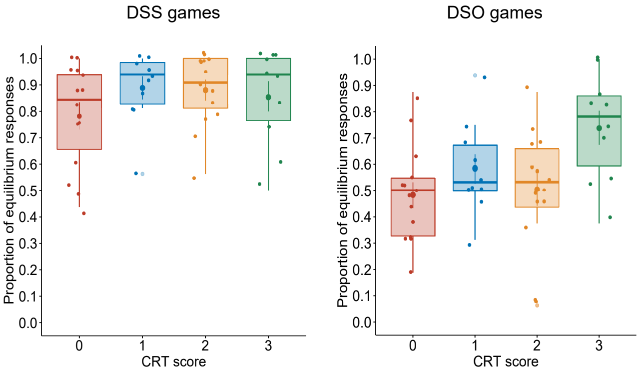

FIGURE 3: Boxplots of proportion of equilibrium choices in DSS and DSO games by CRT score.

Moreover, we tested whether higher CRT levels are associated with higher earnings. Specifically, we calculated the ‘Strategic IQ’, defined as the magnitude of the expected payoffs of players given the frequency distribution of actual choices of potential opponents (Bhatt & Camerer, 2005). In other words, the Strategic IQ expresses the optimality of a strategy given the actual distribution of strategies among potential opponents in the population. Results of a regression with Strategic IQ as dependent variable and CRT as independent variable reveal that CRT score is associated with the Strategic IQ (R^2 = .17, F (1, 46) = 9.42, B = 0.41, p = .004), suggesting that players with high cognitive reflection use a strategy that is more efficient given the actual distribution of level of strategic thinking in the pool (Figure 4). Taken together, these results highlight a robust link between cognitive reflection and strategic sophistication.

2.3.3 Gaze patterns and choices

First, we tested whether the visual analysis of the game matrix is dependent on the type of game (DSS or DSO). We ran a mixed-effects linear model (subject as random effect)

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[6] See Table A1 in section A.3, Appendices, for a correlation table between the collected individual cognitive measures.

[7] We found the same results after removing from the model highly influential observations (= 5) with values of Cook’s D > 4/n (CRT score: R2 = .18, F (1, 41) = 9.01, B = 0.34, p = 0.005. Variables excluded from the model: Raven score, digit span forward, digit span backward, n-back score: p > .05).

[8] We found an effect of the n-back score on the proportion of equilibrium responses in DSS games (B = 0.23, p = .022), but this effect did not reach significance after excluding from the model highly influential observations (= 3) with values of Cook’s D > 4/n (N-back score: B = 0.26, p = 0.081). All the other measures of working memory and fluid intelligence were not significant, even when controlling for highly influential observations.

Table 2: Mixed-effects logistic model of equilibrium response, with subject as random effect and the proportions of the five types of transitions as independent variables

Equilibrium response	B	SE	z	p	95 % CI	
Own-payoffs within-action	−0.07	0.09	−0.77	.439	-0.25	0.11
Own-payoffs between-action	0.07	0.08	0.90	.366	-0.08	0.22
Other-payoffs within-action	0.42	0.08	4.98	<.001	0.25	0.58
Other-payoffs between-action	0.10	0.07	1.43	.153	-0.04	0.24
Intra-cell	−0.21	0.10	−2.23	.025	-0.40	-0.03
N. obs.	1536					
N. independent obs.	48					

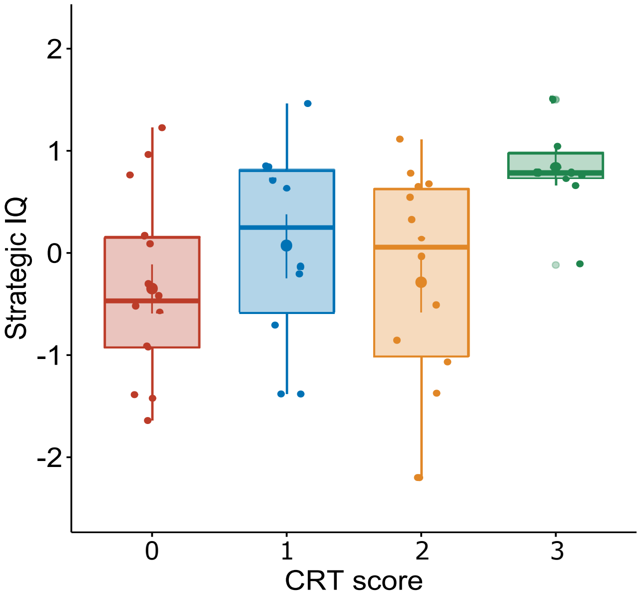

Figure 4: Boxplots of strategic IQ by CRT score.

to identify potential interaction effects between the game type and the five types of relevant payoff transitions. Results do not show any effect of game type in any of the five types of relevant transitions (Table A2 and A3 in section A.3, Appendices). These results are in line with previous findings (Polonio et al., 2015), suggesting that the visual analysis of the game matrix is modulated by top-down attentional mechanisms that are independent of the current payoff structure. For this reason, henceforth gaze patterns will be analyzed independently of the type of game.

Table 3: Multivariate regression with the average proportion of five types of relevant transitions as dependent variable and CRT score as independent variable.

Proportion of transitions	B	SE	z	p	95 % CI	
Own within-action	−0.09	0.15	−0.60	.549	−0.38	0.21
Own between-action	0.05	0.15	0.31	.758	−0.25	0.34
Other within-action	0.46	0.13	3.54	.001	0.20	0.73
Other between-action	0.00	0.15	0.02	.981	−0.29	0.30
Intra-cell	−0.03	0.15	−0.18	.854	−0.32	0.27
N. obs.	48					

In order to identify the attentional indices able to predict strategic sophistication, we ran a mixed-effects logistic regression with equilibrium response as dependent variable, the proportions of the five types of transition as independent variables and subject as random effect. Results of the model (Table 2) show that strategic behavior is accompanied by a higher proportion of other-payoffs within-action transitions (B = 0.42, p < .001) and a lower proportion of intra-cell transitions (B = −0.21, p =.025). The implementation of other-payoffs within-action transitions reflects the attempt at forming precise beliefs about the opponent's move by computing the expected value of each of her two potential actions. This is consistent with the expected behavior of a level-2 player that best responds to the belief that the counterpart is level-1. Intra-cell transitions are consistent with the visual analysis of players who aim to coordinate with the counterpart on a cooperative solution and disregard dominant choices of the two players (Polonio et al., 2015).

2.3.4 CRT and gaze patterns

One of the main goals of the present work is to understand whether cognitive reflection modulates the implementation of gaze patterns underlying the construction of sophisticated game representations. We ran a multivariate regression with our five types of transitions as dependent variables and CRT as independent variable. Results show that CRT score predicted the mean proportion of other-payoffs within-action transitions (R^2 = .21, F = 12.50, B = 0.46, p = .001, significant at Bonferroni-corrected threshold. See Table 3), which we have previously shown to predict the rate of equilibrium choices.[9]

In order to explore the cognitive specificity of this effect, we also ran stepwise backward regressions including our fluid intelligence measures and working memory measures

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[9] Results did not change if excluding from the model influential observations (=2) identified by values of Cook's D > 4/n (Effect of CRT score on other-payoffs within-action transitions: B = 0.46, p = 0.001. No other significant effects found).

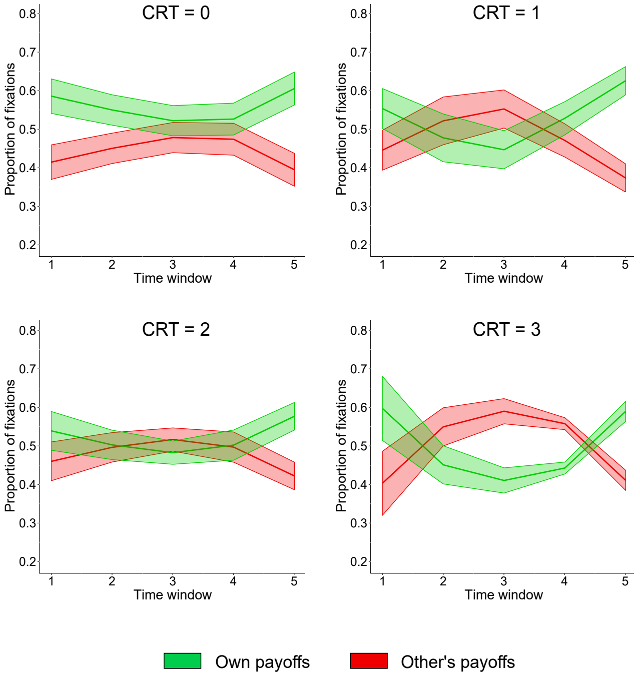

Figure 5: Temporal evolution of proportion of own and other's payoffs fixations for each CRT level. In each trial, we assigned fixations to five time intervals containing the same number of fixations Trial-by-trial proportions of fixations were averaged for each participant and then individual time courses were averaged across participants. Filled areas around lines represent between-subject standard error of the mean (see section A.2 of the Appendices for an exhaustive description of the temporal analysis of fixations).

as independent variables. Results indicate that measures of fluid intelligence and working memory do not have any impact on the average proportion of the five types of relevant transitions (APM, digit span forward and digit span backward: $p > .05$). Results are identical when running the same analyses separately for DSS (effect on other-payoffs within-action transition — CRT: $B = 0.44$, $p = .002$; APM, digit span forward and digit span backward: $p > .05$; no other effects on transition types) and DSO (effect on other-payoffs within-action transition — CRT: $B = 0.45$, $p = .001$; APM, digit span forward and digit span backward: $p > .05$; no other effects on transition types), suggesting that cognitive reflection regulates top-down attentional mechanisms that in turn modulates the visual exploration of game matrices.

Figure 5 shows the time course of the distribution of attention between own and other's payoffs separately for each cognitive reflection level. Low CRT players (CRT = 0) remained primarily focused on their own payoffs during the entire time course of the game. Conversely, high CRT players (CRT = 3) started focusing on own payoffs, then moved to evaluating incentives of their counterpart, and finally they observed again their own payoffs in order to best respond to the opponent's predicted action. This pattern is consistent with the temporal analysis exhibited by strategic players reported in Polonio et al. (2015).

Results of a mixed-effects linear regression confirmed that the CRT level modulates the selective increase of other's player fixations in the middle section of the trial ($B = 0.40$, $p = .031$) and not at the start and at the end of the trial, when attention is mainly focused on players' own incentives for every CRT level (Start: $B = 0.01$, $p = .942$; End: $B = 0.13$, $p = .492$). Crucially, the increase in the magnitude of attention towards the counterpart's incentives between the initial and the middle part of the trial predicts the proportion of equilibrium responses in DSO games ($B = 0.38$, $p = .008$. See Section A.2 of the Appendices for a full description of the temporal analysis). Results of the temporal analysis show that cognitive reflection modulates the players' tendency to switch attention towards the counterpart's incentives after an initial exploration of their own incentives.

2.3.5 CRT, gaze patterns and strategic choices: mediation analysis

In the previous paragraphs, we have shown three main results:

- Visual patterns of information acquisition predicts strategic sophistication in 2x2 games.
- Cognitive reflection predicts strategic sophistication in 2x2 games.
- Cognitive reflection predicts visual patterns of information acquisition in 2x2 games.

Afterwards, we asked whether the relationship between cognitive reflection and strategic sophistication was mediated by visual analysis. We considered only DSO games since we have previously shown that in these matrices the CRT level affects both visual analysis and choices, while in DSS games the CRT score does not modulate equilibrium choices, leaving no room for a mediation effect. To test for the presence of a mediation effect, we ran an additional linear regression with proportion of equilibrium responses as dependent variable and CRT score and proportion of other-payoffs within-action transitions as independent variables (Table A4 in section A.3, Appendices). Interestingly, the effect of CRT on equilibrium responses (observed in Table 1) disappears after including the proportion of other-payoffs within-action transitions as independent variable, indicating full mediation of visual analysis on the relationship between cognitive reflection and strategic sophistication. The mediated effect was tested for significance using the "Mediation" R package (Imai et al., 2010). Confidence intervals were calculated using the bias-corrected and accelerated bootstrap method (BCa) (Di Ciccio & Efron, 1996), a procedure specifically recommended in mediation analysis (Preacher &

Table 4: Results of Causal Mediation Analysis with proportion of other-payoffs within-action transitions as a mediator, CRT score as independent variable and proportion of equilibrium responses as dependent variable. Only DSO games were considered for this analysis.

Effect	Estimated coefficient	95% CI lower bound	95% CI upper bound	p
Average causal mediation effect (ACME)	0.19	0.07	0.39	.002
Average direct effect (ADE)	0.14	-0.13	0.37	.295
Total effect	0.33	0.04	0.57	.021
Proportion mediated	0.58	0.27	5.56	.023

Hayes, 2008). As expected, the average causal mediation effect of proportion of other-payoffs within-action transitions on the relation between CRT score and proportion of equilibrium responses is statistically significant (p = .002, based on 10000 bootstrap samples), accounting for an estimated 58 % of the total effect between CRT score and proportion of equilibrium responses (Table 4).

2.4 Summary

In Experiment 1, we have shown that cognitive reflection is closely associated with strategic behavior in one-shot 2x2 matrix games. First, the CRT score predicts the free parameter τ, expressing the hierarchical level of sophistication in the Cognitive Hierarchy model, as well as the proportion of equilibrium choices in dominance-solvable games requiring strategic sophistication and the Strategic IQ. Crucially, the CRT score predicts also the type of visual analysis employed in the same games. High CRT players performed a higher proportion of other-payoffs within-action transitions, reflecting the attempt at forming precise (non-diffuse) beliefs about the choice of the counterpart. The emergence of this pattern of information acquisition completely mediates the relationship between cognitive reflection and the level of sophistication of choices.

In order to understand the generalizability of these effects, in Experiment 2 we explored the relationships between cognitive reflection, gaze patterns and strategic choices in matrix games characterized by a more complex payoff structure.

3 Experiment 2

3.1 Methods

3.1.1 Participants and procedure

Participants were other 48 students from the University of Trento, Italy (27 females, mean age 23, SD 3.16). Participants performed fourteen 3x3 one-shot matrix games. We used the 14 games reported in Costa-Gomes and Weizsäcker (2008).[10] All games have a unique Nash equilibrium and do not have salient payoffs. Ten of these games are solvable in two, three, or four steps of iterated dominance,[11] while four games have unique Nash equilibrium without dominant strategies.

Before playing the games, participants were instructed on the procedure and were provided with examples and training trials (4 games). Moreover, control questions were administered to verify that task and procedure of payment had been fully understood by participants. If participants failed to answer control questions, instructions were repeated until participant's full comprehension (we report detailed instructions and control questionnaires in section C.1 of the Appendices). The order of games was randomized across participants. Each trial was preceded by a fixation-point positioned in one of four possible locations outside the symbol space.

All participants played in the role of row player and were instructed to choose between row I, row II and row III by keypress.[12] Each game was played only once and no feedback was provided at the end of games. At the end of the fourteen games, three games were randomly selected and the player's choice in each game was paired with the choice of another player in that game. Participants received the sum of the outcomes of the three games in euros (from 3.1 to 29 euros).

Moreover, participants completed the Cognitive Reflection Test (CRT) with the same items used in Experiment 1. We did not collect other control measures of fluid intelligence and working memory, since we have already shown that the effect of reflection, as measured by the CRT, on

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[10] For the full game list, see Figure B1 in section B1, Appendices

[11] Four Games are dominance solvable with two rounds of dominance; five games are dominance solvable with three rounds of dominance; one game is dominance solvable with four rounds of dominance.

[12] In order to pair each participant with an opponent, the 14 games included seven pairs of isomorphic games. Isomorphic games are equivalent in the sense that the second game of each pair is identical to the first except for transposing the players' roles, changing the order of the three actions (for both players), and adding or subtracting a small constant amount from the payoffs of each game. In this way, it was possible to match the choices of row players as they have played in two different roles.

strategic choices or gaze patterns in one-shot matrix games does not seem to be driven by fluid intelligence or working memory.

3.1.2 Eye-tracking procedure and gaze data analysis

The eye-tracking procedure was identical to the one used in Experiment 1.

Concerning gaze data analysis, we defined 18 regions of interest (ROIs) centered on the matrix payoffs. All the ROIs had a circular shape with a size of 36000 pixels, did not overlap and covered 38.8 % of the game matrix area. However, the large majority of fixations (86 %) fell inside the ROIs. All the fixations falling outside the ROIs were discarded. The same gaze variables of Experiment 1 (own and other's payoffs fixations; five types of between-payoffs transitions) were used for eye-tracking analysis in Experiment 2.[13]

3.2 Hypotheses

In Experiment 2, we asked whether the effects observed in Experiment 1 could generalize to more complex payoff structures (3x3). In this regard, recent evidence (Costa-Gomes and Weizsäcker, 2008) has shown that players rarely reach equilibrium in these complex games; rather, they usually implement a maximum of two steps of strategic thinking (level-2) (Polonio & Coricelli, 2019). We do not expect players to regularly play the equilibrium strategy, and the most sophisticated model of choice employed by players should be level-2, which assumes the counterpart to be a level-1 player. We therefore expect the CRT score to be associated with higher levels of strategic thinking (i.e., level-2), and with a higher proportion of level-2 choices.

As in Experiment 1, we hypothesize that the behavior of high CRT players translates in visual patterns of information acquisition meant to predict the opponent's move: in particular, sophisticated players should exhibit a higher proportion of other-payoff within-action transitions, reflecting the attempt at predicting the action with the highest average payoff for the opponent (Bhatt & Camerer, 2005; Costa-Gomes et al., 2001; Devetag et al., 2016; Polonio & Coricelli, 2019). Finally, we expect sophistication in the visual analysis of the game matrix to mediate the relationship between cognitive reflection and strategic choices.

Table 5: Average proportion of choices in accordance with each of the three common models of choice (Level-1 (L1), Level-2 (L2) and Nash Equilibrium (Nash).

		Behavioral model of choice		
	Game ID	L1	L2	Nash
2 steps of iterated dominance	1	0.40	0.29	0.29
	3	0.69	0.21	0.21
	5	0.56	0.35	0.35
	7	0.38	0.33	0.33
		0.51	0.29	0.29
3/4 steps of iterated dominance	2	0.50	0.25	0.50
	4	0.75	0.75	0.25
	6	0.90	0.90	0.10
	8	0.58	0.58	0.58
	9	0.71	0.25	0.71
	10	0.40	0.35	0.35
		0.64	0.51	0.42
Unique Nash (no dominance)	11	0.58	0.35	0.35
	12	0.71	0.71	0.21
	13	0.73	0.23	0.73
	14	0.50	0.38	0.13
		0.63	0.42	0.35
	All	0.60	0.42	0.36

3.3 Results

3.3.1 Behavioral results

In Table 5, we report the proportion of choices in accordance with three common models of choice: level-1 (L1), level-2 (L2) and Nash equilibrium. Consistently with previous results (Costa-Gomes and Weizsäcker, 2008; Polonio & Coricelli, 2019), the model that best explains the average behavior of players, in every class of game, is L1, while players play the Nash equilibrium barely above chance level. In the next paragraph, we will explore whether and how cognitive reflection can account for heterogeneity in strategic sophistication.

3.3.2 CRT and strategic sophistication

As in Experiment 1, we estimated the parameter τ of each of the four CRT groups to investigate whether the CRT score is associated with the level of strategic thinking predicted by the Cognitive Hierarchy model. As in the previous experiment, higher CRT levels are associated with higher τ parameters (CRT = 0, $\tau = 0.59$; CRT = 1, $\tau = 1.40$; CRT = 2, $\tau = 1.12$; CRT = 3, $\tau = 1.54$), suggesting a close association

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[13] As in Experiment 1, a fixation was defined as an interval in which gaze was focused within 1° of visual angle for at least 100 ms (Manor & Gordon, 2003). The proportion of transitions that did not fall in any of the five type of relevant transition was quite high (55 %) but did not correlate with the proportion of equilibrium (Spearman's r = 0.06, p = 0.69) and L2 (r = −0.17, p = 0.24) responses, confirming that they express payoff comparisons that are not crucial for strategy generation and game resolution.

Table 6: For each of the four CRT levels, we report the parameter τ (CH), which reflects the average number of steps of strategic thinking in the Cognitive Hierarchy (CH) model, and the average proportion of L2 responses. Values in brackets represent between-subject standard deviations.

CRT score	N	τ (CH)	Avg. proportion of L2 responses
CRT = 0	14	0.59	0.32 (0.11)
CRT = 1	9	1.40	0.42 (0.15)
CRT = 2	8	1.12	0.41 (0.23)
CRT = 3	17	1.54	0.52 (0.19)

between cognitive reflection and level of strategic sophistication (Table 6). We can see that τ levels are lower than the ones observed in Experiment 1, as expected by the higher complexity of the games. Specifically, the CRT group with the highest average τ (CRT = 3) exhibited a level of strategic thinking between L1 and L2, confirming that in these games players generally implement a maximum of two steps of strategic thinking. For this reason, we will use the proportion of L2 responses as a behavioral measure of level of sophistication in the next analyses. The proportion of L2 choices in 3x3 games was indeed modulated by CRT score (Linear regression, $R^2 = 0.17$, F (1, 46) = 9.48, B = 0.41, p = 0.003).[14] Results do not change when excluding from the model influential observations (= 3) with values of Cook's D > 4/n. ($R^2 = 0.22$, F (1, 43) = 12.05, B = 0.38, p = 0.001). Average proportions of L2 responses for each CRT level are reported in Table 6 and visualized in Figure B2 (left panel) in section B.2 of the Appendices.

In Experiment 1, we found that high CRT score (CRT = 3) was associated with a higher level of Strategic IQ. In Experiment 2, we do not observe any association between CRT score and Strategic IQ ($R^2 = 0.04$, F (1, 46) = 1.71, B = 0.19, p = .197, see Figure B2, right panel, in section B.2 of the Appendices). The absence of a significant effect in Experiment 2 could be explained by the increase of the strategy space in 3x3 games. In fact, in 2x2 games, the L2 strategy constitutes a best response to both L1 and L2 strategies; since the minimum number of steps of strategic thinking observed in 2x2 games is one (L1), the L2 strategy expresses a best response to the large majority of potential opponents in the population. Therefore, players closer to level-2 (CRT = 3) exhibit a higher Strategic IQ. Conversely, in our 3x3 games, the L2 model of choice does not constitute a best response to a L2 or a L0 counterpart and the L2 strategy is not always efficient given the actual distribution of types of players in the population. In other words, in 3x3 games, the heterogeneity of the population's strategy space might have prevented high CRT players from best responding to a high ratio of potential opponents, and from increasing their Strategic IQ significantly.

3.3.3 Gaze patterns and choices

First, we asked whether the visual analysis is influenced by the type of game (2-steps, 3–4 steps, no dominance). We ran a repeated-measures ANOVA with proportion of transitions as dependent variable and type of transition and type of game as independent repeated factors in order to test for the presence of an interaction effect. Results reveal an effect of type of transition (F (4, 376) = 14.79, p < .001) and no effects of type or game (F (2, 376) = 0.92, p = 0.403) or game-transition interaction (F (8, 376) = 0.96, p = 0.466).[15] These results corroborate results of Experiment 1 showing no effect of the game structure on the scan path implemented by participants to analyze matrices. For this reason, gaze patterns will be analyzed independently of the type of game henceforth.

Replicating results of Experiment 1, higher levels of strategic sophistication were accompanied by a higher proportion of other-payoffs within-action transitions (Mixed-model logistic regression of L2 response B = 0.67, p < .001, Table B4 in section B.2, Appendices). Additionally, we observe an effect of own-payoffs between-action transitions (B = 0.22, p = .019).[16] The higher proportion of own-payoffs between-action transitions is consistent with the expected and observed visual pattern of information acquisition of strategic players (Polonio & Coricelli, 2019) who, after having formed beliefs about the expected action of the opponent, best respond to this prediction by looking at their own payoffs within the expected counterpart's action.[17] These results confirm that exploring the incentives of the counterpart and integrating them in a comprehensive representation of the game is crucial to exhibit more sophisticated models of choice, as L2.

3.3.4 CRT and gaze patterns

We tested whether the CRT score predicted visual patterns of information acquisition also in 3x3 games. Consistently with results of Experiment 1, CRT score specifically predicts the mean proportion of other-payoffs within-action transitions among the five relevant transitions (Multivariate regression,

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[14] The same analysis did not return any significant results when using the proportion of equilibrium responses as dependent variable (R2 = 0.02, F (1, 46) = 1.15, B = 0.15, p = .290, Table B1 in section B.2 Appendices). This can be easily explained by the low rate of equilibrium responses.

[15] We report descriptive statistics of gaze pattern across classes of games in Table B2 in section B.2, Appendices.

[16] As expected, given the low proportion of equilibrium responses in our sample, we did not find any effect of type of payoff transitions on the rate of equilibrium responses (Table B3 in section B.2, Appendices)

[17] The absence of an effect of own-payoffs between-action transitions in Experiment 1 corroborate previous results (Devetag et al. 2016; Polonio & Coricelli, 2019) showing that an increase in the action space (as in 3x3 matrices) results in a more precise characterization of the gaze patterns underlying the decision process implemented by the participants.

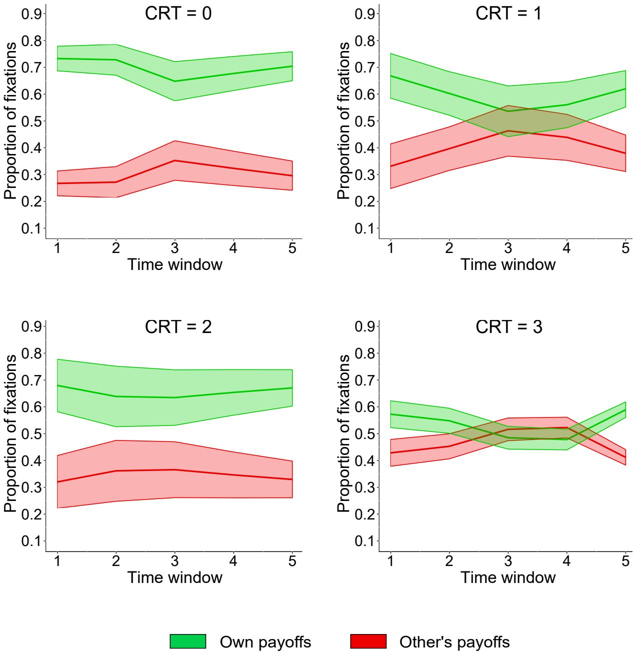

FIGURE 6: Temporal evolution of the distribution of attention between own and other's payoffs fixation by CRT level. Temporal windows were defined using the same method of Experiment 1 (see section A.2 in the Appendices) Filled areas represent between-subject standard errors of the mean.

B = 0.37, p = .009, F (1, 46) = 7.48, R^2 = 0.14, significant at Bonferroni-corrected threshold. See Table B5 in section B.2, Appendices). Results hold even if excluding influential observations (n = 3) with values of Cook's D > 4/n (B = 0.41, p = .001). Moreover, we report an almost significant trend of the CRT score on the proportion of other-payoffs between-action transitions (B = 0.27, p = .059), which reaches significance when excluding from the model influential observations (Cook's D > 4/n, B = 0.36, p = .009).[18] Other-payoffs between-action transitions are relevant in the visual analysis of the payoff matrix since are necessary to spot relationships of dominance between the actions of the counterpart and apply recursive steps of strategic thinking in complex 3 x 3 payoff structures (Polonio & Coricelli, 2019).

We also analyzed the time course of the distribution of attention between own and other's payoffs across CRT levels. As shown in Figure 6, low CRT players were primarily focused on their own payoffs during the entire time course of the game. Conversely, high CRT players started focusing on own payoffs, then increased their level of attention towards the payoff of the counterpart and eventually they focused again their own payoffs in order to best respond to the opponent's predicted action.

The temporal pattern of high CRT players is less neat than the one observed in Experiment 1, probably due to the increased complexity of the payoff structures that pushes players to focus more on own payoffs and play less sophisticated strategies in 3x3 games. In fact, low CRT players largely ignored the counterpart's incentives along the entire time course of the trial. Coherently, results of a mixed-effect linear model indeed show the CRT score modulates the rate of attention towards other's payoffs not only in the middle part of the trial (B = 0.46, p = .007), but also at the beginning (B = 0.50, p = .003) and almost significantly in the final part of the trial (B = 0.33, p = .052).[19]

3.3.5 CRT, gaze patterns and strategic choices: mediation analysis

Finally, we aimed to replicate findings from Experiment 1, showing an effect of full mediation of game visual analysis on the relationship between cognitive reflection and sophistication of choices.

We ran a linear regression with mean proportion of L2 response as dependent variable and CRT score and proportion of other-payoffs within-action transitions as independent variables (Table B6 in section B.2, Appendices). As in Experiment 1, the effect of CRT on the proportion of strategic (L2) responses disappears after including in the model the proportion of other-payoffs within-action transitions, indicating full mediation of game visual analysis on the relationship between cognitive reflection and strategic choices. The average causal mediation effect of proportion of other-payoffs within-action transitions on the relation between CRT score and proportion of L2 responses is statistically significant (p = .003, based on 10000 bootstrap samples, bias-corrected and accelerated bootstrap method), accounting for an estimated 68% of the total effect between CRT score and L2 responses (Table B7 in section B.2, Appendices).

3.4 Summary

Experiment 2 replicated results of Experiment 1 using games characterized by increased relational complexity of the payoff structure. As in the previous experiment, a high CRT score is associated with the tendency to take into consideration other's incentives to form beliefs about her expected action, and predicts the implementation of more sophisticated models of choice (closer to level-2 of the Cognitive Hierarchy model). Moreover, the relationship between cognitive abilities and strategic choices is entirely driven by the mediating effect of the type of visual analysis implemented.

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[18] No other differences in terms of relationship between gaze patterns and CRT score were found when controlling for influence statistics.

[19] The temporal analysis of fixations in Experiment 2 was identical to the one conducted in Experiment 1 (see section A.2 in the Appendices).

4 Discussion

In two eye-tracking experiments, we found that cognitive reflection can predict the ability to take into account others' incentives in the visual exploration of the payoff matrix. This visual analysis is fundamental since it reflects the attempt to predict other's actions and respond to such predictions, which we can consider as the hallmark of strategic behavior. High levels of cognitive reflection also explain the implementation of a higher number of steps of strategic thinking in the decision process, in the framework of Level-k and Cognitive Hierarchy theories. Interestingly, the relationship between cognitive reflection and strategic choices is completely mediated by gaze patterns, suggesting a precise role for cognitive reflection and game representation mechanisms in explaining strategic behavior.

The association between cognitive reflection and lookup patterns suggests that one cause of unsophisticated strategic behavior is the failure to process and represent relevant information accurately. Specifically, individuals characterized by an unreflective cognitive style tend to disregard those payoff comparisons that are necessary to form beliefs about the action of the counterpart and therefore engage in strategic recursive reasoning. Individual cognitive style therefore modulates attentional mechanisms sub-serving one of the core components of mentalizing, namely the understanding of others' preferences (Bilancini et al., 2018). However, this does not imply that low CRT players are *unable* to attribute mental states to others; rather, it suggests that cognitive reflection modulates top-down attentional process of information search and representation necessary to correctly integrate others' incentives in the model of the opponent's decision space. When the complexity of this cognitive operation is high, low CRT agents may implement behavioral rules that simplify the relational structure of the problem (Devetag & Warglien, 2008; Pantelis & Kennedy, 2017). For instance, they may focus primarily on own payoffs (Evans & Krueger, 2014), as suggested by the increased bias towards own payoff in in Experiment 2.

Our results can be easily interpreted in the framework of dual-process theories (Chaiken & Trope, 1999; Epstein et al., 1996; Gawronski & Creighton, 2013; Kahneman, 2003; Sloman,1996; Smith & DeCoster, 2000; Strack and Deutsch, 2004; Evans, 2008), which explain heterogeneity in decision making in terms of reliance on deliberative and intuitive cognitive systems (Alós-Ferrer et al., 2016). In these terms, cognitive reflection expresses the individual tendency to rely more or less on one or the other system (Osman, 2004). Nonetheless, the implementation of unsophisticated strategies in one-shot games may depend on the tendency to initially rely on intuitive processing until errors or inefficiency are detected by the deliberative system (Evans, 1984, 2006; Kahneman, 2003; Travers et al., 2016). This hypothesis is supported by results of Experiment 1 showing that the cognitive reflection level modulates the players' tendency to switch attention towards the counterpart's incentives after an initial exploration of their own payoffs.

Nevertheless, this interpretation does not entail that low CRT players are *unable* to build more exhaustive representation of the interactive decision and to use more sophisticated models of choice. In fact, recent findings (Zonca et al., 2019a) have shown that players using unsophisticated visual analyses and models of choice (i.e., L1 players) can switch gaze patterns and choice towards more sophisticated behavior after exposure to alternative models of choice. In the same way, unreflective players may abandon their initial unsophisticated strategy and increase their level of sophistication after feedback that reveals the inefficiency of their current behavior or the existence of more sophisticated strategies (Verbrugge et al. 2018).

Moreover, our findings highlight a crucial component of the concept of "strategic awareness" advanced by Fehr & Huck (2016). Specifically, the authors suggested that out-of-equilibrium behavior is driven by the lack of understanding of the interactive nature of the game: we indeed propose that a potential cause of this awareness lies in the failure to process task-relevant information exhaustively.

We also found that the visual analysis sustaining the construction of game representations appears to completely mediate the relationship between cognitive reflection and strategic choices. This finding is important since it discloses the nature of this effect, widely reported in recent studies exploring the link between game playing and cognitive abilities (Akiyama et al., 2017; Brañas-Garza et al., 2012; Carpenter et al., 2013; Fehr & Huck, 2016; Kiss et al., 2016; Georganas et al., 2015). Cognitive reflection does not directly affect choices, but rather influences mechanisms of encoding and representation of relevant information in the payoff matrix, which in turn predict sophistication in choices. Moreover, this finding offers new insight about the role of cognitive reflection and representation-building in higher cognition, given that the CRT has been found to predict behavior in several decision-making (Brañas-Garza et al., 2012; Campitelli & Labollita, 2010; Graffeo et al., 2015; Toplak et al., 2011), learning (Don et al., 2016) and reasoning (Hoppe & Kusterer, 2011; Oechssler et al., 2009) tasks. In particular, these results support the idea that the effect of cognitive reflection on complex tasks may reside in its effect of processes of search, encoding and representation of task-relevant information, as suggested in previous studies (Cokely & Kelley, 2009; Sirota et al., 2014; Zonca et al., 2019b).

Taken together, our results stress the importance of processes of representation generation for understanding strategic behavior (Devetag & Warglien, 2008), and ground the sophistication of such processes in the use of rich or miserly information processing, as assessed by individual levels of cognitive reflection. Nonetheless, other cognitive processes may intervene in determining sophistication in interactive decisions. For example, use of recursive thinking might influence performance in games like the Beauty Contest game (Mazzocco et al, 2013), and forward or backward induction may be necessary in multi-step games. Working memory abilities might influence strategic behavior in repeated games, where information about previous trials must be recalled and integrated with novel information. Furthermore, social motives might intervene in the decision process and influence the expected utility of players with other-regarding preferences, who aim to maximize joint, rather than individuals, outcomes (Devetag et al., 2016; Polonio & Coricelli, 2019). We hope that our results could fuel further research into the role of cognitive processes and social motives in explaining strategic behavior in interactive settings.

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