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Cognitive Load in the Multi-player Prisoner's Dilemma Game: Are There Brains in Games?*

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Abstract

We find that differences in the ability to devote cognitive resources to a strategic interaction imply differences in strategic behavior. In our experiment, we manipulate the availability of cognitive resources by applying a differential cognitive load. In cognitive load experiments, subjects are directed to perform a task which occupies cognitive resources, in addition to making a choice in another domain. The greater the cognitive resources required for the task implies that fewer such resources will be available for deliberation on the choice. Although much is known about how subjects make decisions under a cognitive load, little is known about how this affects behavior in strategic games. We run an experiment in which subjects play a repeated multi-player prisoner's dilemma game under two cognitive load treatments. In one treatment, subjects are placed under a high cognitive load (given a 7 digit number to recall) and subjects in the other are placed under a low cognitive load (given a 2 digit number). According to two different measures, we find evidence that the low load subjects behave more strategically. First, the behavior of the low load subjects converged to the Subgame Perfect Nash Equilibrium prediction at a faster rate than the high load subjects. Second, we find evidence that low load subjects were better able to condition their behavior on the outcomes of previous periods.

Keywords: bounded rationality, experimental economics, experimental game theory, public goods game, strategic sophistication, rational inattention

JEL: C72, C91

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1 Introduction

There have been advancements in the understanding of play in games based on the conceptualization that players devote heterogenous levels of cognition to deliberation on their strategy (Stahl and Wilson, 1994, 1995; Nagel, 1995; Costa-Gomes et al., 2001; Camerer et al., 2004). These advancements specify that the players exhibit heterogenous levels of strategic sophistication. This conceptualization is often supported by observing play in a game and determining whether these models improve the fit with the observations. In addition to comparing the predictions with the observations, these models are also supported by the measurement of data related to the level of cognition. For instance studies measuring the decision to lookup relevant and available information,[1] eyetracking studies which measure the location of the attention of the subjects,[2] measures of the intelligence of the subjects,[3] and even neurological data[4] have been seen as providing evidence in support of these models which posit heterogenous strategic sophistication.

In a rough sense, these experimental papers ask whether one can observe the effects of cognition on strategic behavior. In these studies, researchers perform a measure of cognition or a measure related to the level of cognition and compare this with the observed behavior in games. In this paper we take a complementary approach. Rather than measure the level of cognition or perform a measure related to the level of cognition, we manipulate the level of cognition. This procedure has the advantage that, since we can randomly assign subjects to a level of cognition, our results are not possibly driven by an unobserved characteristic which is only related to cognition. Although we do not study behavior which would provide direct evidence on hierarchical models, similar to these papers, we are interested in examining the role of cognition in strategic outcomes. In this sense, the present paper is complimentary way of asking, "Are there brains in games?"

In the experiment described below, we find a relationship between the heterogenous ability

[1] See Camerer et al. (1993), Johnson et al. (2002), Crawford (2008), Costa-Gomes et al. (2001) and Costa-Gomes and Crawford (2006).

[2] For instance, see Wang et al. (2010) and Chen et al. (2010).

[3] For instance, see Bayer and Renou (2011), Brañas-Garza et al. (2011), Devetag and Warglien (2003), and Gill and Prowse (2012).

[4] For instance, see Coricelli and Nagel (2009).

to devote cognitive resources to a strategic interaction and behavior in the interaction. This heterogeneity arises because we apply a differential cognitive load on subjects who are playing the game. In cognitive load experiments, subjects are directed to perform a memorization task in parallel to making a choice in another domain. This additional memorization task occupies cognitive resources which cannot be devoted to deliberation on the choice. In this sense, the condition of subjects under a larger cognitive load could be thought of as similar to the condition of subjects with a diminished ability to reason.

Much is known about the behavior of subjects under a cognitive load. For instance, the literature finds that subjects under a larger cognitive load tend to be more impulsive and less analytical. However, little is known about how cognitive load affects play in strategic games.[5]

This experiment seeks to clarify the relationship between cognitive load and behavior in games. Further, due to the similarity between the condition of being under a cognitive load and the condition of having a diminished ability to reason, our experiment attempts to shed light on the relationship between intelligence and behavior in games. One might be tempted to conclude that the diminished ability to reason would generate obvious predictions; for instance that subjects under a smaller cognitive load would behave in a manner which is closer to the equilibrium behavior. However, the predictions on this front are far from obvious due to the observation of positive relationship between a measure of intelligence and cooperation in the repeated prisoner's dilemma game.[6]

In our experiment, we impose a cognitive load on subjects who are playing a repeated multi-player prisoner's dilemma game. In each period, subjects are told to memorize a number. In the low load treatment, this is a small number and therefore relatively easy to remember. In the high load treatment, this is a large number and therefore relatively difficult to remember. The subjects then play a four-player prisoner's dilemma game. After the subjects make their choice in the game, they are asked to recall the number. As suggested above, subjects in the low load condition are better able to commit cognitive resources to deliberation on their

[5] Researchers have also studied the effects of the contraints on the complexity of strategies on outcomes in the finitely repeated prisoner's dilemma game. For instance, see Neyman (1985, 1998). Also see Béal (2010) for a more recent reference. Our study can be thought to perform a similar exercise in the laborary.

[6] For instance, see Jones (2008).

action in the game.

Of course, the Subgame Perfect Nash Equilibrium (SPNE) of the finitely repeated multi-player prisoner's dilemma game is for each player to select the uncooperative action in every period. As with most experimental investigations of the prisoner's dilemma game, we do not observe this. We do find that the behavior of the subjects in the low load condition converges to the SPNE prediction at a faster rate than those in the high load treatment. We also find that low load subjects are better able to condition their strategy on previous outcomes. These findings suggest that our manipulation of the availability of cognitive resources affects strategic behavior in our setting.

1.1 Related Literature

The cognitive load literature finds that subjects under a larger cognitive load tend to be more impulsive and less analytical. These differences in behavior stem from the fact that those under a larger cognitive load are less able to devote cognitive resources to reflect on their decision. For instance, Shiv and Fedorikhin (1999) describe an experiment in which subjects were given an option of eating an unhealthy cake or a healthy serving of fruit. The authors found that the subjects were more likely to select the cake when they were under a high cognitive load.

Much is known about how the cognitive load affects subjects in nonstrategic settings. In addition to being more impulsive and less analytical (Hinson et al., 2003) it has been found that subjects under a cognitive load tend to be more risk averse and exhibit a higher degree of time impatience (Benjamin et al., 2012), make more mistakes (Rydval, 2011), have less self control (Shiv and Fedorikhin, 1999; Ward and Mann, 2000), fail to process available information (Gilbert et al., 1988; Swann et al., 1990), perform worse on gambling tasks (Hinson et al. 2002), are more susceptible to a social label (Cornelissen et al., 2007), and have different evaluations of the fairness of outcomes (Cornelissen et al., 2011; van den Bos et al., 2006; Hauge et al., 2009).

However, to our knowledge, there are only two papers which investigate the relationship between the manipulation of cognitive load and behavior in games, Roch et al. (2000) and Cappelletti et al. (2011). Roch et al. (2000) found that subjects under the low cognitive load condition requested more resources in a common resource game. However, in Roch et al. the subjects were not told the penalty if the sum of the group's requests exceeded the amount to be divided. As a result, one cannot determine whether the cognitive load manipulation implied differences in strategic behavior or differences in the regard for instructions which are not incentivized.

Cappelletti et al. (2011) studied behavior in the ultimatum game and varied the ability of subjects to deliberate by manipulating both time pressure and cognitive load. The authors found that time pressure affects the behavior of both proposer and responder. However, the authors found that cognitive load does not affect behavior as either a proposer or responder. In contrast, we find that cognitive load does affect strategic behavior in our setting. The difference in the efficacy of the cognitive load manipulation is likely due to the differences in its incentivization. We further discuss this issue below.

There is a recent interest in the relationship between intelligence and preferences.[7] This literature finds a negative relationship between intelligence and both risk aversion and time impatience. We note the similarities between the findings in the intelligence literature and those in the cognitive load literature. Therefore, to the extent that manipulating cognitive load is analogous to manipulating the intelligence of the subject, we now discuss the literature on the relationship between measures of intelligence and behavior in games.[8] For instance, Burnham et al. (2009) found a relationship between a measure of intelligence and strategic behavior in a beauty contest game. Jones (2008) found a relationship between cooperation in the repeated prisoner's dilemma and the average SAT scores at the university where the experiment was conducted.[9] Devetag and Warglien (2003) found a relationship between the

[7]See Benjamin et al. (2012), Brañas-Garza et al. (2008), Burks et al. (2008), Dohmen et al. (2010), Frederick (2005) and Oechssler et al. (2009). See Ben-Ner et al. (2004), Branstätter and Güth (2002), Chen et al. (2011a) and Millet and Dewitte (2007) for more on the relationship between social preferences and measures of intelligence.

[8]Also see Bajo et al. (2011), Ballinger et al. (2011), Bayer and Renou (2011), Brañas-Garza et al. (2012), Brañas-Garza et al. (2011), Chen et al. (2009), Chen et al. (2011b), Gill and Prowse (2012), Jones (2011), Palacios-Huerta (2003), Putterman et al. (2011) and Rydval (2011).

[9]See Rydval and Ortmann (2004) for a similar result.

working memory capacity of a subject and the congruence of play to equilibrium behavior. We contribute to this literature, rather than measuring cognition, by manipulating cognition and examining the implications in a strategic setting.[10]

Finally note that our paper relates to the rational inattention literature.[11] These models assume that decision makers are unable to process all of the available information, however they optimally allocate their attention in order to make decisions. Central to these models, it is assumed that agents have constraints on their ability to process information. In our experiment, we provide evidence of these constraints in that subjects under a smaller cognitive load are better able to condition their play on the outcomes of previous periods.

2 Method

A total of 60 subjects participated in the experiment. The subjects were graduate and undergraduate students at Rutgers University-Camden. The experiment was conducted in two sessions of 16, one session of 12, and two sessions of 8. The experiment was programmed and conducted with the software z-Tree (Fischbacher, 2007).

Subjects were matched with three other subjects in which they were to play a repeated prisoner's dilemma game. The subjects were told that the group would remain fixed throughout the experiment.[12] The subjects were given no additional information about the group members.

The individual decision was to select X (the cooperative action) or Y (the uncooperative action). Of the four subjects in the group, if x play X then selecting X yields a payoff of $20x$ points whereas selecting Y yields $20x + 40$. The exchange rate was \$1 for every 150 points. Additionally, the subjects were paid a \$5 show-up fee. While making a decision in the game, the subjects were provided with the payoffs in two formats. The subjects were told

[10] Somewhat related to our approach, Bednar et al. (2012) describe an experiment in which subjects simultaneously played two distinct games with different opponents. The authors found that behavior in a particular game was affected by the corresponding paired game. Also see Savikhina and Sheremeta (2012).

[11] See Sims (2003) for an early reference. See Mackowiak and Wiederholt (2009) and Reis (2006) for subsequent efforts. Also see Wiederholt (2010) for an overview of the field.

[12] The instructions were given via power point slides. The slides, along with any experimental material, are available from the corresponding author upon request.

that both formats presented identical information. See the appendix for the screen shown to the subjects during their decision in the game.

Before play in each period, the subjects were given 15 seconds in which to commit a number to memory. The subjects were aware that they would be asked to recall the number after their choice was made in the game. There were two cognitive load treatments: in the low load treatment, subjects were directed to memorize a 2 digit number, and in the high load treatment, subjects were directed to memorize a 7 digit number. There were 26 subjects in the low load treatment and 34 in the high load treatment. The subjects were told that they would only receive payment in the periods in which they correctly recalled the number. In other words, the subjects would receive nothing for the periods in which they incorrectly recalled the number.

After each period, subjects were given feedback regarding play in the game, however they were not given feedback about their performance on the memorization task. Across all treatments, the composition of 12 of the 15 groups was homogenous, in that they contained only a single load treatment. However, there were 3 groups which were mixed in the sense that that 2 subjects were in the low load treatment and 2 were in the high load treatment. We refer to this group as *mixed*. We did not provide any information about the possibility of different treatments or mixed groups.

To summarize the timing in each period, subjects were given the number (7 digits or 2 digits), they made their choice in the game, they were asked to recall the number, and they were given feedback on the game outcome but not on the memorization task outcome. Each of these stages were designed so that the subject would not proceed to the next stage until each subject completed the prior stage. This procedure was repeated for 30 periods, with a new number in each period. The average amount earned was $14.76.

At the conclusion of period 30, the subjects answered the following manipulation check questions on a scale of 1 to 7: Which featured into your decisions between X and Y, your prudent side or your impulsive side (1 prudent, 7 impulsive)? How difficult was it for you to recall your numbers (1 very difficult, 7 not very difficult)? How difficult was it for you to decide between X and Y (1 very difficult, 7 not very difficult)? How distracting was the memorization task (1 very distracting, 7 not very distracting)? and How many of the memorization tasks do you expect that you correctly answered (1 none correct, 7 all correct)?

The z-Tree output specified the time remaining when the Click to Proceed button was pressed. However, there were instances where the output suggested that the decision was made with 99999 seconds remaining. This output seems to have occurred if the "Click to Proceed" button was pressed before the clock could begin. In the stage in which the number was given to the subjects, we recorded the 56 instances of the 99999 output as 16, because 15 seconds were allotted. In the stage in which the number was to be recalled, we recorded the 5 instances of the 99999 output as 16, because 15 seconds were allotted.

2.1 Discussion of the Experimental Design

Before we describe the results, we discuss the design of the experiment. Although the cognitive load manipulation is common, to our knowledge, we are the only example of a paper in which the manipulation is repeated. As a result, it was not obvious to us whether we should balance the experiment so that each subject would undergo the high and low loads an equal number of times. However, we decided to keep the subjects in a single treatment throughout the experiment. In part, this decision was due to the results in Dewitte et al. (2005) which reports that the effects of the cognitive load manipulation can be lasting. Also note that we decided to use a 7 digit number as the high load manipulation because it is standard in the literature and because Miller (1956) found that this tends to be near the limit of the memory of subjects.[13]

The bulk of the cognitive load literature does not incentivise the memorization task.[14] To our knowledge, Benjamin et al. (2012) and Cappelletti et al. (2011) are the only examples of experiments with such material incentives. Cappelletti et al. (2011) paid the subjects per correct digit. On the other hand, we pay the full amount earned in the game for correct recall and we pay nothing for incorrect recall. However, like Cappelletti et al. (2011), we do

[13] Also, see Cowan (2001) for more recent view on the memory capacity literature.

[14] Although there is evidence that subjects perform better on tasks which require attention when the tasks are incentivized. See Camerer and Hogarth (1999).

not provide feedback regarding the accuracy of the memorization task. We make these two design decisions in order to reduce the ability of the subjects to strategically allocate cognitive resources. In particular, we want to avoid providing an incentive for the subjects to seek an interior solution to the trade-off between devoting cognitive resources to the memorization task and deliberation on the game. In other words, we designed the experiment in such a way that the subjects had an incentive to guarantee that sufficient cognitive resources were devoted to the successful recall the number, then devote any remaining resources to deliberation on their behavior in the game.

Another means of incentivising the cognitive load, without inducing possible differences in payment, is to pay the subjects based on the rank of correct answers within their treatment. While this procedure has the advantage that payments across treatments would be equal, in our view this is less satisfactory than our design. First, in order to make these instructions comprehensible, we would have to explain to the subjects that there are different cognitive load treatments. We had a preference to avoid informing the subjects that there would be different treatments because we were concerned that the subjects in the high load treatment might resent their difficult task, and this resentment might affect their behavior. Second, the rank payment scheme would possibly encourage the subjects to seek an interior solution to the trade-off between devoting cognitive resources to the memorization task and deliberation on the game. Again, if subjects can reduce their memory load, without significant financial penalty, then it is likely that we would not observe the effects of the treatment. When considering the relative advantages of the rank payment scheme and our design, it would seem that the latter is preferable.

Also note that we designed the experiment so that the subject would only enter the following stage when all other players completed the preceding stage. This was done in order to mitigate the ability of the subjects to strategically decide the timing of their decisions. In other words, due to our design, there was little incentive for the subjects in the low load condition to quickly leave the stage where they were given the number. Additionally, the subjects in the high load condition could not quickly make their decision in the prisoner's dilemma game, in order to spill their number in the memorization task. We suspect that our results would be stronger if we allowed subjects to immediately proceed to the subsequent stage.

Finally, we study the four-player prisoner's dilemma[15] because it has a few attractive features for the purpose of examining the role of cognitive load in strategic games. The game is relatively simple because the decision is binary and the game is linear. In order to keep the game from being too complicated, we did not elect to use a more general public goods game. On the other hand, the four-player version requires more thought than the two-player version because outcomes depend on the actions of three opponents, rather than just one opponent. Further, we were concerned that the subjects could be familiar with the two-player version and would possibly import this prior experience into the experiment. For this reason, we employed the four-player version.

3 Results

3.1 Manipulation checks and overview of the data

All five of the manipulation check questions demonstrated differences between the high and low load treatments. Specifically, those in the high load treatment reported being more impulsive ($Z(58) = 1.77$, $p = 0.076$),[16] having more difficulty in recalling the number ($Z(58) = 4.19$, $p < 0.001$), having more difficulty in deciding on an action in the game ($Z(58) = 1.39$, $p = 0.16$), found the memorization task to be more distracting ($Z(58) = 4.10$, $p < 0.001$), and expected to correctly recall the number with lower precision ($Z(58) = 2.56$, $p = 0.011$) than those in the low load treatment. Further, the subjects in the high load treatment spent a significantly longer time committing the number to memory ($M = 9.15$, $SD = 4.93$) than did the subjects in the low load treatment ($M = 1.19$, $SD = 2.20$), $Z(1798) = 32.62$, $p < 0.001$.

Despite its difficulty, we were surprised by the success of the high load subjects on the memorization task. In the high load treatment, 820 of the 1020 (80.4%) of the memorization

[15] See Komorita et al. (1980).

[16] These are the results of two-sided Mann-Whitney tests between the high and low load subjects.

tasks were preformed correctly. By comparison, 766 of 780 (98.2%) of the memorization tasks in the low load were preformed correctly.

Finally, we provide an overview of the rates of cooperation in the experiment. In Table 1, we list the rates of cooperation by treatment and the period in which it occurred.

Table 1. Cooperation rates by treatment and period

Periods	$1-5$	$6-10$	$11-15$	$16-20$	$21-25$	$26-30$	Total
High Load	0.494	0.406	0.365	0.341	0.318	0.365	0.381
Low Load	0.515	0.400	0.438	0.408	0.315	0.192	0.378
Z-statistic	0.363	-0.102	1.291	1.180	-0.041	-3.254	-0.137
p-value	0.716	0.919	0.197	0.238	0.967	0.0011	0.891

We report the results of Mann-Whitney tests for the difference between the cooperation rates for the high and low load treatments. We perform these tests on blocks of 5 periods and also on the aggregate data. The former tests have 298 degrees of freedom and the latter test has 1798 degrees of freedom.

Table 1 suggests that there does not exist a large difference between the overall rates of cooperation of the high and low load subjects. When considering the periods in blocks of 5 or the aggregate data, we only find a significant difference between the treatments in the final 5 periods. This suggests that, as the end of the game approached, the low load subjects played more strategically than the high load subjects. We also note that considering the periods in blocks of 10 can also be helpful. While there is no difference in cooperation in the first 10 periods ($Z(598) = 0.187$, $p = 0.852$), the low load subjects cooperate more that the high load subjects in the middle 10 periods ($Z(598) = 1.75$, $p = 0.080$), and the low subjects cooperate less in the final 10 periods ($Z(598) = -2.30$, $p = 0.021$). A glance at Table 1 also suggests that subjects across both treatments converged to the SPNE behavior. We now conduct a more detailed analysis of the behavior of the subjects.

3.2 Differences in behavior

We begin the analysis with cooperation in the game. Here, our dependent variable obtains a value of 1 if the cooperative action (X) was selected and 0 otherwise. We use a dummy variable where 1 indicates that the subject was in the low load treatment and 0 otherwise. We also use a dummy variable indicating whether the period was within the final 5 periods. We use a dummy variable indicating whether the group was mixed and therefore contained subjects from both the high and low load treatments. Note that the fixed-effects regressions below, and throughout the paper, are specific to the subject rather than the group. While the groups are fixed throughout the experiment, there also exists subject-specific unobserved heterogeneity which remained constant throughout the experiment. As a result, we conduct subject-specific, not group-specific, fixed-effects. See Table 2 for the results of these regressions.

Table 2. Logistic regressions of cooperation

	(1)	(2)	(3)	(4)	(5)
Period	-0.0336^{***}	-0.0399^{***}	-0.0248^{***}	-0.0282^{***}	-0.0418^{***}
	(0.00572)	(0.00627)	(0.00891)	(0.00956)	(0.00813)
Low Load	–	–	0.333^{*}	–	–
			(0.199)		
Last 5	–	–	0.0432	0.0547	0.483^{**}
			(0.179)	(0.194)	(0.235)
Last 5-Low Load Interaction	–	–	-0.0233^{**}	-0.0335^{***}	-1.294^{***}
			(0.0116)	(0.0130)	(0.326)
Last 5-Mixed Interaction	–	–	–	–	0.292
					(0.387)
Fixed-effects?	No	Yes	No	Yes	Yes
-2 *Log L*	2355.44	2049.69	2351.29	2042.82	2032.31
$LR\ \chi^2$	35.19^{***}	340.94^{***}	39.34^{***}	347.81^{***}	358.32^{***}

We provide the coefficient estimates with standard errors in parentheses, where * indicates significance at 0.1, ** indicates significance at 0.05, and *** indicates significance at 0.01. Each regression has 1800 observations.

The analysis summarized in Table 2 confirms our intuition from Table 1. First, note that there is strong evidence of convergence to the SPNE prediction. In every specification involving the period, our results indicate that subjects played less cooperatively across time. We also find weak evidence that subjects in the low load treatment were more cooperative than the subjects in the high load treatment. Additionally, we find that the actions of the subjects in the low load treatment converged to the SPNE behavior at faster rate than those in the high low load treatment. Further, this relationship continues to hold when we account for the mixed nature of the groups. We summarize this analysis with the following result.

Result 1 Across both treatments, behavior converged to the SPNE behavior, however the convergence was faster for the low load subjects.

We note that our result is not sensitive to the specification of the convergence. A model with an interaction between the period and the low load dummy, rather than the interaction between the Last 5 dummy and the low load dummy, produces very similar results. However, in a model in which both interaction terms are included, the interaction involving Last 5 is significant and that involving the period is not significant.[17]

3.3 Differences in cognitive resources or differences in expected payments?

One potential explanation for the difference in the behavior of the subjects in the high and low load treatments relates to a possible difference in the expected payments across treatments. It is possible that the high load subjects expected to earn less than the low load subjects, and the difference in expectations, rather than the difference in the cognitive load, implied the difference in behavior. Although it would seem difficult to argue that Result 1 was driven by a difference in payment expectations, it remains a possibility. While it is not possible to determine the precise difference in the payment expectations, it is possible to look for evidence that the difference in behavior was motivated by the income effect rather than the cognitive load.

One possibility is that the subjects in the high load treatment completely forgot the number, and therefore selected the action in the game with the knowledge that they would not receive payment in that period. If this was the case then we would expect to see subjects quickly entering an incorrect number so that they could use this additional time to rest and therefore perform better in the subsequent period. In other words, we will look for evidence that high load subjects quickly entered incorrect responses to the memorization task. In Table 3 we demonstrate the relationship between the memorization task and the time remaining when the stage was exited. In particular, we provide the number of correct responses, the number of total responses, and the percent correct by the time remaining when the stage was exited. Recall that subjects were given 15 seconds in which to provide the number.

[17] These results are available from the corresponding author upon request.

Table 3. The number of correct memorization task responses, total responses, and percent correct by time remaining and treatment

	Time Remaining	14 or more	13 or 12	11 or 10	9 or 8	7 or 6	5 or less
High Load	Correct	21	365	281	91	41	21
	Total	22	400	347	130	60	61
	Percent	96%	91%	81%	70%	69%	34%
Low Load	Correct	414	287	46	16	1	2
	Total	421	287	48	17	1	6
	Percent	98%	100%	96%	94%	100%	33%

In Table 3 we observe that relatively few incorrect responses to the memorization task occur early in the stage. This suggests that it was not common for the subject to leave the game stage having forgotten the number because there is evidence that the subjects exerted effort to correctly perform the memorization task. The data summarized in Table 3 seems to be consistent with the hypothesis that the subjects in both treatments attempted to correctly perform the memorization task, albeit the high load subjects took longer and did so with less success.

While the results of Table 3 suggest that the subjects attempted to correctly respond to the memorization task, it is possible that response times would not capture the perceived likelihood of payment. To account for this possibility, we employ a different measure of the subject's expectation of payment in that period: whether the subject correctly responded to the memorization task in that period. Here we preform an analysis, similar to that summarized in Table 2, with the exception that we include a variable Correct, which assumes a value of 1 if the memorization task in that period was performed correctly, and 0 otherwise. We present a summary of this analysis in Table 4.

Table 4. Logistic regressions of cooperation

	(1)	(2)	(3)	(4)	(5)
Period	-0.0336^{***}	-0.0399^{***}	-0.0348^{***}	-0.0417^{***}	-0.0417^{***}
	(0.00572)	(0.00627)	(0.00740)	(0.00813)	(0.00813)
Low Load	–	–	0.168	–	–
			(0.111)		
Last 5	–	–	0.441^{**}	0.536^{**}	0.482^{**}
			(0.209)	(0.224)	(0.235)
Last 5-Low Load Interaction	–	–	-1.005^{***}	-1.294^{***}	-1.293^{***}
			(0.294)	(0.326)	(0.326)
Last 5-Mixed Interaction	–	–	–	–	0.288
					(0.387)
Correct	−0.211	−0.0637	−0.214	−0.0510	−0.0469
	(0.149)	(0.186)	(0.155)	(0.185)	(0.185)
Correct p-value	0.16	0.73	0.17	0.78	0.80
Fixed-effects?	No	Yes	No	Yes	Yes
$-2\ Log\ L$	2353.45	2049.58	2341.07	2032.79	2032.24
$LR\ \chi^2$	37.18^{***}	341.05^{***}	49.56^{***}	357.84^{***}	358.39^{***}

We provide the coefficient estimates with standard errors in parentheses, where * indicates significance at 0.1, ** indicates significance at 0.05, and *** indicates significance at 0.01. We also provide the p-value for the Correct variable. Each regression has 1800 observations.

First, we note that Result 1 is not affected by the presence of the Correct variable. In other words, given our measure of the confidence that the subject would correctly perform the memorization task in that period, we still observe convergence to the SPNE behavior and that this convergence is faster for the low load subjects. Second, we note that the Correct variable is not significant in any of the regressions. Hence, there does not appear to be a relationship between cooperation and successfully performing the memorization task in that period.

Alternatively, we could account for the possibility of differences in the expectations of payment by excluding observations in which the subject incorrectly performed the memorization task. Consider an analysis similar to that summarized in Table 2, with the exception that we only include the 1586 observations in which the memorization task was performed correctly in that period. These results are qualitatively similar to that summarized in Table 4.[18] In light of the analysis discussed above, we offer the following result.

[18] These results are available from the corresponding author upon request.

Result 2 We do not find evidence that the subjects were motivated by a difference in payment rather than by a difference in cognitive load.

3.4 Differences in game outcomes

Despite these differences in behavior, it is unclear whether there are corresponding differences in game outcomes. We perform an analysis, similar to that summarized in Table 2, except that the dependent variable is the outcome of the game and we perform the analysis with ordered multinomial logistic regressions. For the purposes of the analysis below, we do not account for the accuracy in the memorization task. In other words, in the regressions below, we use the payoffs which would have been earned had the memorization task been performed correctly. We describe this variable as *provisional payoffs*. Here we consider provisional payoffs because we want to avoid introducing unwarranted differences between the treatments. Note that up to this point, we what now describe as provisional payoffs, we referred to as game outcomes. We will henceforth use the term provisional payoffs. These regressions are summarized in Table 5.

Table 5. Ordered multinomial logistic regressions of provisional payoffs

	(1)	(2)	(3)	(4)	(5)
Period	-0.0311^{***}	-0.0337^{***}	-0.0325^{***}	-0.0350^{***}	-0.0350^{***}
	(0.0050)	(0.00508)	(0.00654)	(0.00663)	(0.00663)
Low Load	–	–	0.214^{**}	–	–
			(0.095)		
Last 5	–	–	0.219	0.249	0.189
			(0.182)	(0.184)	(0.191)
Last 5-Low Load Interaction	–	–	-0.387^{*}	-0.468^{**}	-0.480^{**}
			(0.233)	(0.236)	(0.237)
Last 5-Mixed Interaction	–	–	–	–	0.328
					(0.293)
Fixed-effects?	No	Yes	No	Yes	Yes
-2 *Log L*	4921.75	4615.37	4915.91	4611.31	4610.04
$LR\ \chi^2$	38.60^{***}	344.99^{***}	44.44^{***}	349.04^{***}	350.32^{***}

Ordered multinomial logistic regressions with a dependent variable of provisional payoffs earned in the stage game. We provide the coefficient estimates with standard errors in parentheses, where * indicates significance at 0.1,** indicates significance at 0.05, and *** indicates significance at 0.01. Each regression has 1800 observations.

We find evidence that the provisional payoffs were decreasing across periods. This result is not surprising because, as we found earlier, the behavior of the subjects converged to the SPNE behavior. We also find that the low load dummy variable is significant, although in this analysis significant at 0.05. Again, this is not surprising because we found a similar relationship between the low load dummy and cooperation. Also not surprisingly, we find that the low load subjects obtained significantly lower payoffs in the last 5 periods than did the high load subjects.

Although we do not present this analysis in Table 5, we note that these results are not affected by a variable indicating whether the memorization task was correctly performed in that period. Further, we note that our results continue to hold when the analysis is conducted as a linear regression rather than as ordered multinomial logistic regressions. We summarize this analysis with the following result.

Result 3 The provisional payoffs of the subjects in both treatments converged to the provisional payoffs predicted by the SPNE outcome. Also the provisional payoffs of the low load subjects converged to that predicted by SPNE faster than did that of the high load subjects.

3.5 Differences in ability to condition on previous outcomes

To this point, we have found that the low load subjects were more strategic in that their behavior converged to the SPNE prediction at a faster rate than did the behavior of the high load subjects. Now we explore another measure of strategic behavior: whether the low load subjects were better able to condition their play on past outcomes. In order to investigate this possibility, we offer a model of cooperation which is possibly dependent on previous outcomes. In the analysis described below, we assume that the subject considers features of these previous outcomes to be state variables upon which play can be conditioned. In other words, we do not intend to provide a model of learning.

We now describe two such variables upon which the subject could condition. One possibility is that the subjects would condition play on the number of other players in the group who played cooperatively in the previous period. In other words, we compare the action selected in period t with the number of other group members who played cooperatively in period $t-1$. In the description below, we refer to this variable as *Lagged Number of Others Playing X*. Note that this variable can range from 0 to 3. Another possibility is that subjects would condition play on the change in cooperation between the previous period and the period preceding that. In other words, we compare the action selected in period t with the difference between the number of other group members who played cooperatively in period $t-1$ and the number who played cooperatively in period $t-2$. We refer to this variable as *Lagged Change in Others Playing X*. Note that this variable can range from -3 to 3. Finally, we include the three relevant interaction terms. The results of this analysis are summarized in Table 6.

Table 6. Fixed-effects logistic regressions of cooperation

	(1)	(2)	(3)	(4)
Lagged Number of Others Playing X	0.0523	–	−0.0733	−0.196
	(0.0849)		(0.125)	(0.128)
Interaction with Low Load	0.0677	–	0.431**	0.397**
	(0.133)		(0.197)	(0.199)
Lagged Change in Others Playing X	–	0.0753	−0.0142	0.0786
		(0.0621)	(0.110)	(0.112)
Interaction with Low Load	–	−0.112	−0.317**	−0.312**
		(0.097)	(0.137)	(0.138)
Lagged Number of Others Playing X -Lagged Change Interaction	–	–	0.0947*	0.0825
			(0.0517)	(0.0521)
Period	–	–	–	−0.0340***
				(0.00736)
-2 *Log L*	1987.63	1894.62	1885.26	1863.54
LR χ^2	302.54***	313.43***	322.79***	344.52***

We provide the coefficient estimates with standard errors in parentheses, where * indicates significance at 0.1, ** indicates significance at 0.05, and *** indicates significance at 0.01. Due to the nature of the lagged variables, regression (1) has 1740 observations and regressions (2) − (4) have 1680 observations.

In regression (1) we do not observe a significant relationship. In particular, we do not observe a relationship between cooperation and the number of others playing cooperatively in the previous period. Further there is not a significant difference between the treatments regarding the sensitivity to the number of others playing cooperatively in the previous period. In regression (2), we observe a similar lack of significance as in regression (1). There we do not find evidence of a relationship between cooperation and the lagged change in others playing cooperatively. Finally, we do not observe a significant difference between the treatments regarding the sensitivity to the changes in cooperation.

However, in regression (3) significant relationships emerge. Although again neither measure of previous cooperation is significant, we do observe a differential sensitivity to both measures of previous cooperation. We find that the low load subjects were more sensitive to the number of others playing cooperatively in the previous period than the high load subjects. Additionally, the low load subjects were more sensitive to the change cooperation than the high load subjects. In regression (4) we also account for the period in which the decision was made. Here we still observe significance of the differential sensitivity for both measures.

Consider the signs of the significant variables in regressions (3) and (4). We note that the interaction between the treatment and Number of Others Playing X is positive. This suggests that low load subjects were more likely than high load subjects to cooperate in response to a high level of cooperation in the previous period. We also note that the interaction between the treatment and the Change in Others Playing X is negative. This suggests that low load subjects were more likely than high load subjects to play uncooperatively in response to an *increase* in cooperation between the previous period and the period preceding the previous period.

Although the lack of significance in regressions (1) and (2) above, seems dissonant to the significance in regressions (3) and (4), intuition on the matter is relatively straightforward. Behavior is not exclusively a function of the level of cooperation in the previous period or exclusively a function of the change in the cooperation, but it is a function of both variables. Consider a subject making a decision regarding cooperation, where 2 of the 3 other subjects played cooperatively in the previous period. By itself, the number of cooperators in the previous period has no context, and is therefore not a sufficient basis on which to make the choice. If the number of cooperators rose from 1 to 2, the subject could regard that as different from the situation in which the number of cooperators fell from 3 to 2. Therefore, it is not surprising that significant relationships only emerge when we consider both the level of cooperation and the change in cooperation.

To further analyze the relationship between cognitive load and the sensitivity of cooperation to previous outcomes, we run the following fixed-effects logistic regressions. In the first regression, we restrict attention to high load subjects. In the second regression, we restrict attention to low load subjects. The results are summarized in Table 7.

Table 7. Restricted fixed-effects logistic regressions of cooperation

	High Load	Low Load
Lagged Number of Others Playing X	-0.0706	0.354^{**}
	(0.125)	(0.154)
Lagged Change in Others Playing X	0.0252	-0.385^{***}
	(0.123)	(0.145)
Lagged Number of Others Playing X -Lagged Change Interaction	0.0639	0.138^{*}
	(0.0677)	(0.0802)
-2 *Log L*	1128.28	756.487
$LR\ \chi^2$	126.12^{***}	197.078^{***}
Observations	952	728

We provide the coefficient estimates with standard errors in parentheses, where * indicates significance at 0.1, ** indicates significance at 0.05, and *** indicates significance at 0.01.

The High Load regression provides no evidence of a relationship between cooperation and the variables. By contrast, the Low Load regression indicates that each of the variables attains a level of significance. In particular, the number of others playing cooperatively is significantly related to the cooperation of the low load subjects at 0.05. Further, the lagged change in others playing cooperatively is related to cooperation for the low load subjects at 0.01. Together the results in Tables 6 and 7 suggest that the low load subjects were more sensitive to previous outcomes than were the high load subjects. We summarize this analysis with the following result.

Result 4: There is evidence that the low load subjects were better able to condition their behavior on previous outcomes than the high load subjects.

4 Conclusion

So are there brains in games? Our results suggest a qualified "yes." Given our manipulation of the availability of cognitive resources in our particular strategic environment, we found that differences in cognitive resources imply differences in strategic behavior. While we found that behavior of both high and low load subjects in the multi-player prisoner's dilemma converged to the SPNE behavior, we also found that the behavior of the low load subjects converged to the SPNE prediction at a faster rate than that of the high load subjects. Additionally, we found evidence that the low load subjects could, better than high load subjects, condition their behavior on previous outcomes.

The relationship between cognitive resources and play in games is also of interest to researchers who study nonequilibrium models. In response to the mounting evidence that subjects rarely play according to the equilibrium predictions, researchers have been turning their attention to nonequilibrium models which can account for hierarchical levels of thinking (Camerer et al., 2004; Costa-Gomes, et al. 2001). It would seem natural to expect that the intelligence of the subject would be related the level of strategic sophistication of the subject. However, Georganas et al. (2010) found that the mapping of measures of intelligence to the estimated hierarchical level of thinking varies across games. While there could be other reasons for this negative result,[19] evidence of this kind is crucial in supporting existing nonequilibrium models or in suggesting modifications to existing models. While the repeated nature of our experiment does not provide direct evidence related to the cognitive hierarchy literature, our paper suggests that it could be fruitful to investigate the relationship between the nonequilibrium models and the intelligence of subjects, through the application of a differential cognitive load.

We also note that the predictions of rational inattention have been studied in the laboratory.[20] The results of our experiment suggest that manipulating the ability to process information via cognitive load could be a productive supplement to efforts to observe behavior consistent with rational inattention.

[19] See Crawford et al. (2012).
[20] See Cheremukhin et al. (2012).

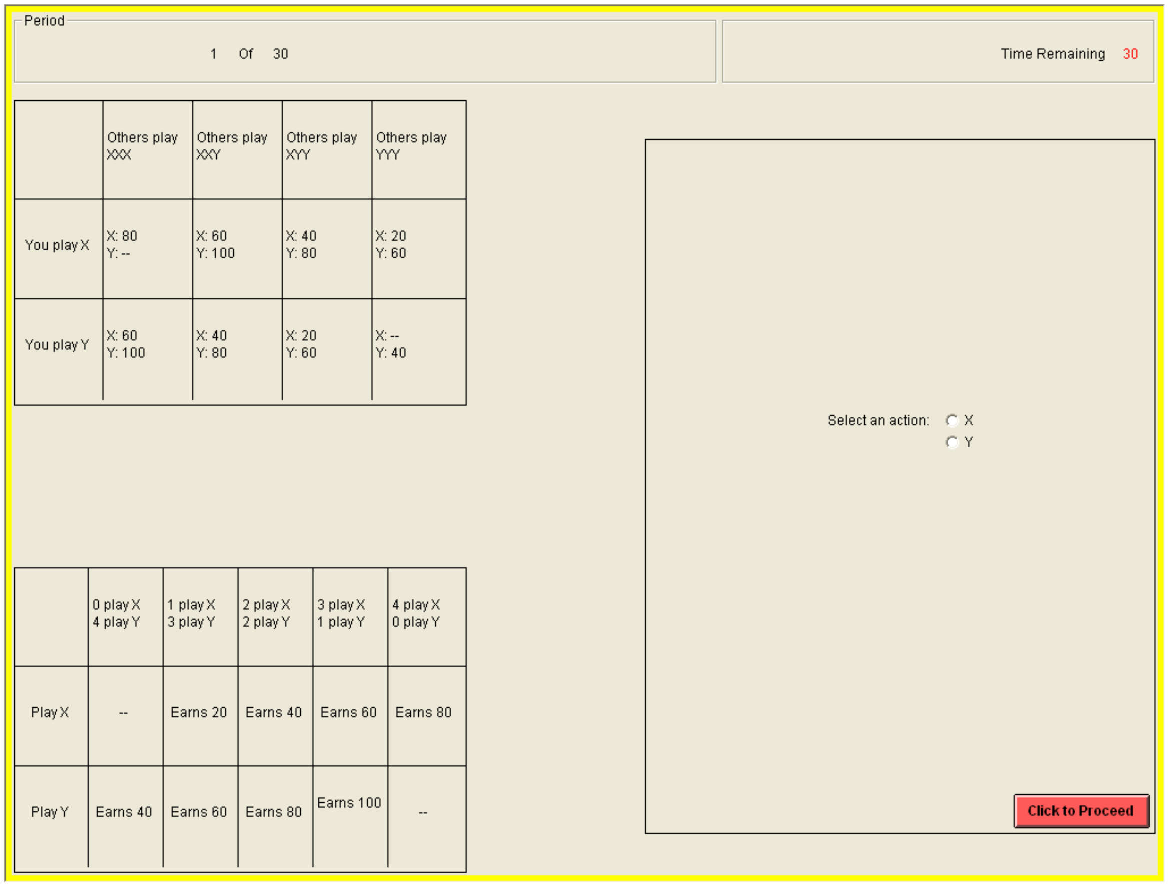
There remain several interesting and unanswered questions. For instance, it is unclear how the results would be affected by a game other than the multi-player prisoner's dilemma. In other words, it is unclear how our results would be affected by an increase (i.e., a public goods game or auction) or a decrease (i.e., a two-player prisoner's dilemma) in the complexity of the game. We hope that future work will examine the relationship between cognitive load effects and the complexity of games.

Another unanswered question relates to the significance of the incentives regarding the memorization task. While our cognitive load manipulation was successful, and we did not find evidence of an income effect, it is possible that the subjects were motivated by differences in payments across treatments. In other words, since payment was only made when the memorization task was correct, and the memorization task for the high load subjects was more difficult, it is possible that the subjects acted differently as a result of the financial incentives rather than as the result of the cognitive load. We hope that future work can address this issue.

Finally, note that we only applied a cognitive load during the stage in which the subjects selected an action in the game. We conjecture that our results would be strengthened if the load was applied during both the game decision stage and the feedback stage. However, we leave it to future work to test this conjecture.

Appendix

The screen during the game decision:



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