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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). We find that the individual behavior of the subjects in the low load condition converges to the Subgame Perfect Nash Equilibrium prediction at a faster rate than those in the high load treatment. However, we do not find the corresponding relationship involving outcomes in the game. Specifically, there is no evidence of a significantly different convergence of game outcomes across treatments. As an explanation of these two results, we find evidence that low load subjects are better able to adjust their choice in response to outcomes in previous periods.

Preliminary and incomplete
Suggestions welcome

Keywords: cognitive resources, experimental economics, experimental game theory, public goods game

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. In particular, it is conceptualized that higher levels within the hierarchy are associated with greater sophistication. This conceptualization is often supported by observing play in a game and determining whether the hierarchical model improves 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 subject,[2] and even neurological data[3] have been seen as providing evidence in support of these hierarchical models.

In a rough sense, these papers ask the questions, "Are there brains in games?" and "If so, what else can we say?" In our paper, rather than measure the level of cognition or measure data related to the level cognition, we manipulate the level of cognition. In this sense, the present paper is another way of asking, "Are there brains in games?" and "If so, what else can we say?"

In the experiment described below, we find a relationship between the heterogenous ability 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 about the choice. In this sense, subjects under a larger cognitive load, can be thought to mimic the condition of

[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 Coricelli and Nagel (2009).

having 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 the cognitive load affects play in strategic games.[4]

This experiment seeks to begin to clarify the relationship between cognitive load and behavior in games. Further, due to the similarity between cognitive load and the diminished ability to reason, the experiment seeks to sheds 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 larger cognitive load will be more cooperative in the prisoner's dilemma game. However, the predictions on this front are far from obvious due to recent findings of a positive relationship between the measure of intelligence and cooperation in the repeated prisoner's dilemma game.[5]

In our experiment, we impose a cognitive load on subjects who are playing 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, the number is large 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 in order to deliberate on their action in the game.

Of course, the Subgame Perfect Nash Equilibrium 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

[4]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.

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

this. We do find that the individual behavior of the subjects in the low load condition converges to the Subgame Perfect Nash equilibrium prediction at a faster rate than those in the high load treatment. However, we do not find the corresponding relationship involving game outcomes. Specifically, there is no evidence of a significantly different convergence of game outcomes across treatments. A potential explanation for these two results, is our finding that subjects in the low load treatment are better able to adjust their strategy in response to the outcome in the previous period than are those in the high load treatment. As a result, they are better able to identify advantageous, temporary situations in which additional surplus could be captured. Further, this agility offsets the trend towards playing uncooperatively. These results combine to suggest that the availability of cognitive resources affects strategic behavior.

1.1 Related Literature

A typical cognitive load experiment would direct subjects to engage in a task which would require mental effort, in addition to making a choice in a different domain. One treatment would be given a relatively easy task (low load treatment) and the other would be given a relatively difficult task (high load treatment). The experimenter would then measure the differences in behavior between the treatments. This literature finds that subjects under a larger cognitive load tend to be more impulsive and less analytical because those in the high load treatment 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 rather than the fruit when they were under the 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., 2006), make more mistakes (Ryvdal, 2007), 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).

There is a literature which examines the relationship between the level of cognition and play in games, without explicitly manipulating the cognitive load. For instance, Chen et. al. (2009) measure the working memory of subjects and examine behavior in double auctions. The authors find some evidence that subjects with a higher working memory perform better. Devetag and Warglien (2003) find a relationship between the working memory capacity of a subject and the congruence of play to that predicted by equilibrium. Also Bednar et. al. (2010) describe an experiment in which subjects simultaneously play two distinct games with different opponents.[6] The authors find that behavior in a particular game is affected by corresponding paired game.

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. (2008). 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 were more than the amount to be divided. As a result, one cannot determine whether the cognitive load manipulation implied differences in strategic behavior or simply differences in the regard for norms which are not incentivized.

Cappelletti et. al. (2008) study behavior in the ultimatum game and vary the ability of the subject to deliberate by manipulating time pressure and cognitive load. The authors find that time pressure affects the behavior of both proposer and responder. However, the authors find that cognitive load does not affect behavior as either a proposer or responder.

[6] Also see Savikhina and Sheremeta (2009).

In contrast, we find that cognitive load does affect behavior in our setting. The difference in efficacy of the manipulation is likely due to the differences in the incentivization of the memorization task. We discuss this issue further 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. Note the similarity to the findings 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 small literature on the relationship between intelligence and behavior in games. Burnham et. al. (2009) demonstrate a relationship between a measure of intelligence and strategic behavior in a beauty contest game. In other words, the authors find that subjects with a higher measure of intelligence select actions which are closer to the Nash Equilibrium of the beauty contest.

On the other hand, Jones (2008) finds a relationship between cooperation in the repeated prisoner's dilemma and the average SAT scores at the university where the experiment was conducted.[8] In other words, Jones finds a negative relationship between a measure of intelligence and strategic behavior in the prisoner's dilemma game.

Therefore, to the extent that an increased cognitive load simulates the effect of a reduced ability to reason, the two papers discussed above would seem to make opposite predictions in our setting. Burnham et. al. (2009) would seem to predict that subjects in the high load treatment will exhibit more cooperation in the prisoner's dilemma game and Jones (2008) would seem to predict that outcomes in the high load treatment will exhibit less cooperation in the prisoner's dilemma game. The experiment which we describe below will help distinguish between these two predictions.

The answer, as it turns out, is a bit more subtle. Across all periods, we find little difference between either the individual behavior or the game outcomes of the subjects in the high and

[7] See Frederick (2005), Benjmin et. al. (2006), Burks et. al. (2008), Dohmen et. al. (2010), and Chen et. al. (2011).

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

low load treatments. However, we find that the individual behavior of the low load subjects converge to the SPNE behavior at a faster rate than high load subjects. We also find that subjects in the low load treatment are better able to condition on past outcomes than are high load subjects.

Finally, note that economists have become interested in studying the response times of subjects.[9] Research has found that longer response times are associated with more strategic and less automatic reasoning. As we are manipulating the ability of the subjects to devote cognitive resources to the problem, the response time will prove to be a useful measure in its efficacy. In other words, we use the response time as a measure of the cognitive resources devoted to the problem.

2 Method

A total of 60 subjects participated in the experiment. The subjects were graduate and undergraduate students of 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.[10] 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, and $4-x$ play Y 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 matrix in two forms, which they were told are identical. See the appendix for the screen shown to the subjects during their decision in the game.

[9] For instance, Brañas-Garza and Miller (2008), Piovesan and Wengström (2009), and Rubinstein (2007)

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

Before play in each period, the subject was 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 periods in which they correctly recalled the number and that they would receive nothing for the periods in which they incorrectly recalled their number.

After each period, subjects were given feedback regarding play in the game, however they were given no information about their performance on the memorization task. Across all treatments, the composition of 12 of the 15 groups were 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*. The subjects were told nothing about the composition of their group.

To summarize the timing in each period, subjects were given the number (7 digits of 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 the memorization task outcome. Each of these stages were designed so that the subject would not proceed to the next stage until each subject completes the prior stage. This procedure was repeated for 30 periods, with a new number in each period. The amount earned by the subjects ranged from \$6.47 to \$20.20, with a mean of \$14.76.

At the conclusion of period 30, the subjects answered the following 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. In the output, there appeared instances of a time remaining of 99999. 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, we recorded the 56 instances of an output of 99999 as 16 because there were 15 seconds allotted. In the stage in which the game was played, we recorded the 2 instances of an output of 99999 as 31 because there were 30 seconds to decide.

2.1 Discussion of the Experimental Design

Before we get into the results, we discuss some issues related to the design of the experiment. Although the cognitive load manipulation is rather 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) finds that this tends to be near the limit of the memory of subjects.[11]

Also note that the bulk of the cognitive load literature does not incentivise the memorization task. To our knowledge, Benjamin et. al. (2006) and Cappelletti et. al. (2008) are the only examples of experiments with such material incentives. Cappelletti et. al. (2008) pays 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. (2008), we provide no feedback regarding the accuracy of the memorization task. We make

[11] Also, see Cowan (2001) for an updated view on the memory capacity literature.

these two design decisions in order to reduce the ability of the subject to strategically allocate cognitive resources. In particular, we want to avoid providing an incentive for the subject to seek an interior solution to the trade-off of cognitive resources for the memorization task and deliberation on the game.

We designed the experiment so that the subject would only enter the following stage when all other players completed the current 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 experimental design, there was little incentive for the subjects in the low load condition to quickly leave the stage where they are given their number because they would not immediately proceed to the game stage. 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, because they would not immediately proceed to the relevant stage.

We study the four-player prisoner's dilemma[12] 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. For the sake of simplicity, we did not elect to use a more general public goods game. However, the four-player version requires more thought than the two-player version because outcomes depend on the actions of three, and not just one, opponent. Further, most of the subjects are familiar with the two-player version and would likely import this prior experience into the experiment. For this reason, we employed the four-player version.

3 Results

All five of the manipulation check questions demonstrated significant differences between the high and low load treatments. Specifically, those in the high load treatment reported being more impulsive ($p = 0.038$), having more difficulty in recalling the number ($p < 0.001$), having more difficulty in deciding on an action in the game ($p = 0.098$), found the memorization task

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

to be more distracting ($p < 0.001$), and expected to correctly recall the number with lower precision ($p = 0.005$) than those in the low load treatment.[13] Further, the subjects in the high load 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 ($M = 1.19$, $SD = 2.20$), $t(1798) = 42.1$, $p < 0.001$.

We now begin the analysis of the individual behavior of the subjects. To do so, we perform a series of logistic regressions with the choice in the game as the dependent variable. Here a value of 1 indicates that the cooperative action (X) was selected and 0 indicates that that the uncooperative action (Y) was selected. We use a type dummy where 1 indicates the low load treatment and 0 indicates the high load treatment. We use a dummy variable indicating whether the group was mixed and therefore contained subjects from both the high and low load treatments. Finally, we use a dummy variable indicating whether the memorization task in that period was correct or incorrect. Note that the regressions below account for the subject-specific fixed-effects and each have $n = 1800$. See Table 1 for the results of these regressions.

	(1)	(2)	(3)	(4)	(5)
Period	-0.0399^{***}	–	-0.0267^{***}	-0.0267^{***}	-0.0267^{***}
	(0.00627)		(0.00801)	(0.00801)	(0.00801)
Low Type	–	0.0961	0.5849	0.6405	0.6517
		(0.6654)	(0.7110)	(0.5829)	(0.5838)
Period-Low Type Interaction	–	–	-0.0336^{***}	-0.0336^{***}	-0.0336^{***}
			(0.0130)	(0.0130)	(0.0130)
Mixed	–	–	–	-0.1251	-0.1316
				(2.5609)	(2.5611)
Mixed-Low Type Interaction	–	–	–	0.5650	0.5632
				(2.4751)	(2.4754)
Correct	–	–	–	–	-0.0650
					(0.1849)
-2 *Log L*	2049.69	2091.41	2042.90	2042.90	2042.78
LR χ^2	340.94^{***}	299.22^{***}	347.73^{***}	347.73^{***}	347.86^{***}

Table 1: Fixed-effects logistic regressions with a dependent variable of choice, where *** indicates significance at 0.01

[13] These are the results of a one-sided t-test between the subjects under high and low loads.

First, note that there is strong evidence of learning across periods. In every specification involving the period, our results indicate that subjects played less cooperatively across time. In other words, perhaps not surprisingly, we see convergence to the Subgame Perfect Nash Equilibrium behavior. Although perhaps surprisingly, across periods, there was little difference between the choice of subjects in the high and low treatments. In each of the four specifications involving the low type dummy, the variable does not achieve significance. However, the differences between the treatments emerge when we account for time. The actions of the subjects in the high load treatment converged to the equilibrium behavior at faster rate than those in the low load treatment. This relationship continues to hold when we account for the mixed nature of the groups or whether the subject correctly preformed the memorization task in that period. Hence, there was convergence to the Subgame Perfect Nash Equilibrium behavior for all types, however the convergence was faster for the low load subjects.

One potential explanation for the faster convergence for the low load treatment is that the high load treatment, due to the differential difficulty of the memorization task, expects to earn less money than the low load treatment. As a result, the behavior of the high load subjects converge to the low paying equilibrium prediction less quickly than the low load subjects. However regression (5) provides evidence against this possibility: there is no significant relationship between choice and whether the subject correctly performed the memorization task in that period.

The natural question is then, "Are the cognitive load treatments thinking differently about the game?" To answer this question, we analyze the response times of the subjects in selecting an action in the game. We run the following three regressions with the time remaining as the dependent variable In other words, the size of our dependent variable is increasing in the speed of the decision. In each regression below, we account for fixed-effects and have $n = 1800$. The results are summarized in Table 2.

	(1)	(2)	(3)
Period	0.247^{***}	–	0.193^{***}
	(0.0148)		(0.0196)
Low Type	–	-3.90^{***}	-5.85^{***}
		(1.51)	(1.47)
Period-Low Type Interaction	–	–	0.126^{***}
			(0.0297)
R^2	0.43	0.34	0.44

Table 2: Fixed-effects linear regressions with a dependent variable of time remaining in the game decision, where *** indicates significance at 0.01

Again there appears to be a great deal of learning across periods. In both specifications in which the period is included, there is a positive relationship between the period and the speed of the decision. This suggests that as the experiment proceeded, the game decision became more automatic and required fewer cognitive resources. The results of the regressions involving type suggest that the subjects in the low load treatment reflected on the decision longer than did the high load subjects. Finally, the result of regression (3) suggests that the low load subjects exhibited stronger learning across periods than did the subjects in the high load treatment, as demonstrated by the positive interaction term.

Note the relationship between Table 2 and regressions (1)-(3) in Table 1. Indeed, in our view, the results of Table 2 suggest an explanation for the results of Table 1. As previous research has indicated, the response time is associated with more strategic and less automatic reasoning. Therefore, the significant, positive estimates of the period coefficients in Table 2 suggest that the subjects are becoming familiar with the game. This suggests an explanation for the observation of the convergence to the Subgame Perfect Nash Equilibrium behavior. The results of Table 2 also suggest that the low load subjects are becoming familiar with the game at a faster rate than the high load subjects. Again this suggests an explanation for the result that the individual behavior of subjects in the low load treatment were converging to the Subgame Perfect behavior at a faster rate than the high load subjects.

It is also interesting to note that, unlike Table 1, Table 2 demonstrates a significant relationship with the treatment dummy. In particular, we observe that subjects in the high load treatment were responding faster than the low load subjects. A possible explanation for this relationship is that the high load subjects exhibited a lower marginal benefit of time thinking about the game, because of the more difficult memorization task, which they must subsequently complete. Therefore, these differences provide an explanation for the observation that the high load subjects make their selection in the game at a faster rate.

Despite these differences in individual behavior, the corresponding differences for game outcomes were not significantly different across treatments. In particular, we do not find the same differential convergence of payoffs as we did for choice. We perform the following regressions, with the payoffs earned in the game as the dependent variable. 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. For this reason, we describe the dependent variable to be *provisional payoffs*. 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. In each regression below, we account for fixed-effects and have $n = 1800$. These regressions are summarized in Table 3.

	(1)	(2)	(3)	(4)	(5)
Period	−0.313***	–	−0.263***	−0.263***	−0.264***
	(0.0489)		(0.0650)	(0.0650)	(0.0650)
Low Type	–	−3.33	−1.57	−1.57	−1.81
		(4.69)	(4.88)	(4.88)	(4.89)
Period-Low Type Interaction	–	–	−0.114	−0.114	−0.113
			(0.0987)	(0.0987)	(0.0987)
Mixed	–	–	–	8.00*	8.23*
				(4.64)	(4.64)
Mixed-Low Type Interaction	–	–	–	7.33	7.29
				(6.56)	(6.56)
Correct	–	–	–	–	1.38
					(1.50)
R^2	0.17	0.15	0.17	0.17	0.17

Table 3: Fixed-effects linear regressions with a dependent variable of provisional payoffs earned in the stage game, where * indicates significance at 0.1, and *** indicates significance at 0.01

We find that the provisional payoffs were decreasing across periods. This result is not surprising because, as we found earlier, the individual behavior of the subjects was converging to the Subgame Perfect behavior. We also find that the low type dummy variable is not significantly related to provisional payoffs. Again, this is not surprising because we did not find the analogous relationship between the low type dummy and individual behavior. However, what is surprising is that, the provisional payoffs of the low treatment subjects do not converge at a rate different than that of the high load subjects. This is surprising because, in the individual behavior regressions, there was a strong difference in the convergence of the high and low treatments. Also note that these relationships involving period, type, and period-type interaction are robust to accounting for the mixed nature of the groups and whether the subject correctly performed the memorization task in that period.

In both specifications involving the mixed group dummy, we see that there is a relationship between the mixed group variable and payoffs which is marginally significant. This suggests that subjects in mixed groups did better than subjects in homogenous groups. However, within these mixed groups, there was no difference between the high and low treatments. In other words, conditional on being in a mixed group, those in the low load did not have a significantly different provisional payoff than those in the high treatment. Finally, we note that the correct dummy is not significantly related to provisional payoffs.

Perhaps the most surprising aspect of the results to this point, is the strong significance of the period-type interaction in Tables 1 and 2, and its lack of significance in Table 3. On the one hand, we found that the individual behavior in the low load treatment converged to the Subgame Perfect behavior faster than those in the high load treatments. These results are found in Table 1. On the other hand, we found that the analogous result did not hold for provisional payoffs. Specifically, the provisional payoffs of the high and low load treatments did not converge at a different rate. These results are found in the Table 3. We now consider a possible explanation for these two seemingly dissonant results: perhaps the low load subjects were better able to condition on previous outcomes, and this extra agility offset the trend of playing uncooperatively.

In order to explore this explanation, we run fixed-effects logistic regressions with choice as the dependent variable. As in the previous analysis, a 1 indicates that the cooperative action was selected and 0 indicates that that the uncooperative action was selected. As we hope to summarize the play in previous periods, we employ a variable which indicates 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 possible measure of previous play is 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 in 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. In the regressions below, we account for fixed-effects. Due to the nature of the lagged variables, regression (1) has $n = 1740$, and regressions (2) and (3) have $n = 1680$. The results are summarized in Table 4.

	(1)	(2)	(3)
Low Type	0.157	0.526	-0.220
	(0.705)	(11.7)	(11.7)
Lagged Number of Others Playing X	0.0523	–	-0.0733
	(0.0849)		(0.125)
Interaction with Low Type	0.0677	–	0.431**
	(0.133)		(0.197)
Lagged Change in Others Playing X	–	0.0753	-0.0142
		(0.0621)	(0.110)
Interaction with Low Type	–	-0.112	-0.317**
		(0.0970)	(0.137)
Lagged Number of Others Playing X	–	–	0.0947*
-Lagged Change Interaction			(0.0517)
-2 *Log L*	1987.63	1894.62	1885.26
LR χ^2	302.54***	313.43***	322.79***

Table 4: Fixed-effects logistic regressions with a dependent variable of choice, where * indicates significance at 0.1, ** indicates significance at 0.05, and ***

indicates significance at 0.01

In regression (1) we do not observe a significant relationship. As previous analysis suggests, the treatment type is not related to choice. Also, we do not observe a relationship between choice and the number of others playing cooperatively in the previous period. Further there is not a significant difference between the sensitivity of the high load subjects to the number of others playing cooperatively in the previous period and the sensitivity of the low load subjects.

In regression (2), we observe a similar lack of significance as that in regression (1). Again, we observe that the type variable is not significantly related to choice. We observe that the lagged change in others playing cooperatively is not significantly related to choice. Finally, we do not observe a significant relationship between the sensitivity of the high load subjects to the change in the cooperation and the sensitivity of the low load subjects.

However, in regression (3) significant relationships emerge. Again, the cognitive load type variable is not significant, nor are either of the measures of previous cooperation. But, we do observe a differential sensitivity to both measures of previous cooperation. The low load types are more sensitive to the number of others playing cooperatively in the previous period than the high load types. Additionally, the low load types are also more sensitive to the change in the numbers of those playing cooperatively than the high load types.

Consider the signs of the variables indicating that the behavior of the low load subjects was more sensitive than that of the high load subjects to previous outcomes. We note that the interaction between the treatment and Number of Others Playing X is positive. This suggests that low load subjects are more likely than high load subjects to cooperate in response to a high level of cooperation in the previous period. We also note that interaction between the treatment and the Change in Others Playing X is negative. This suggests that low load subjects are 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 regression (3), 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. Consider a subject making a decision regarding choice, 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 decision maker would regard that as different from the situation in which the number of cooperators fell from 3 to 2. Therefore, significant relationships only emerge when we consider the level of cooperation and the change in cooperation.

To further analyze the role of type in the sensitivity of choice to previous outcomes, we run the following fixed-effects logistic regressions. In regression (1), we restrict to only the high load subjects. In regression (2) we restrict to only the low load subjects. The results are summarized in Table 5.

	(1)	(2)
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	0.0639	0.138^{*}
-Lagged Change Interaction	(0.0677)	(0.0802)
$-2\ Log\ L$	1128.28	756.487
$LR\ \chi^2$	126.12^{***}	197.078^{***}
n	952	728

Table 5: Fixed-effects logistic regressions with a dependent variable of choice, where * indicates significance at 0.1, ** indicates significance at 0.05, and *** indicates significance at 0.01

The results of regression (1) suggest that neither the number of others playing cooperatively in the previous period, nor the lagged change in others playing cooperatively, nor their interaction is significantly related to choice for the high load types. By contrast, the results of regression (2) indicate that each of the variables attains some level of significance. In particular, the number of others playing cooperatively is significantly related to choice of the low load subjects at the 0.05 level. Further, the lagged change in others playing cooperatively is related to choice for the low load subjects at the 0.01 level. Together the results in Tables 4 and 5 suggest that the choice of the low load subjects was more sensitive to previous outcomes than the choice of the high load subjects.

We now test the robustness of the result that the low load subjects were more sensitive to previous play than the high load types. Although we find that the result is in general robust, we also find that in one specification, the significance is greatly reduced. Here we perform the identical analysis to that in summarized in Table 4. However, here we also account for the mixed nature of the groups and the time effects. In the regressions below, we account for fixed-effects and have $n = 1680$. We summarize these results in Table 6.

	(1)	(2)	(3)	(4)
Low Type	−0.220	−0.503	−0.343	0.251
	(11.7)	(0.626)	(0.633)	(0.714)
Lagged Number of Others Playing X	−0.0733	−0.0733	−0.196	−0.157
	(0.125)	(0.125)	(0.128)	(0.129)
Interaction with Low Type	0.431**	0.431**	0.397**	0.281
	(0.197)	(0.197)	(0.199)	(0.210)
Lagged Change in Others Playing X	−0.0142	−0.0142	0.0786	0.0623
	(0.110)	(0.101)	(0.112)	(0.112)
Interaction with Low Type	−0.317**	−0.317**	−0.312**	−0.248*
	(0.137)	(0.137)	(0.138)	(0.142)
Lagged Number of Others Playing X	0.0947*	0.0947*	0.0825	0.0764
-Lagged Change Interaction	(0.0517)	(0.0517)	(0.0521)	(0.0522)
Mixed	–	−2.00	−1.98	−2.18
		(66.1)	(65.6)	(65.1)
Mixed-Low Type Interaction	–	2.40	2.38	2.59
		(66.1)	(65.6)	(65.1)
Period	–	–	−0.0340***	−0.0236**
			(0.00736)	(0.00929)
Period-Low Type Interaction	–	–	–	−0.0277*
				(0.0153)
-2 *Log L*	1885.26	1885.26	1863.54	1860.22
LR χ^2	322.79***	322.79***	344.52***	347.83***

Table 6: Fixed-effects logistic regressions with a dependent variable of choice, where * indicates significance at 0.1, ** indicates significance at 0.05, and ***

indicates significance at 0.01

In order to facilitate the robustness check, regression (1) in Table 6 is identical to regression (3) in Table 4. Regression (2) accounts for the mixed nature of the groups, and the differential sensitivity of the low subjects to previous play remains significant. Regression (3) also accounts for the period of the decision, and again the differential sensitivity of the low subjects to previous play remains significant. However, when we account for the mixed nature of the groups, the period and the period-type interaction, as we do in regression (4), we see that the differential sensitivity of the low load types is diminished. In particular we see that the differential sensitivity to the number of others playing cooperatively in the previous period is not significant at any level. Further, the differential sensitivity to the change in cooperation is only significant at the 0.1 level.

3.1 Discussion

In the experiment described above, we found that behavior of both high and low load subjects in the multi-player prisoner's dilemma converged to the Subgame Perfect behavior. However, across all periods, we did not find a difference in the behavior of the high and low treatments. When we consider the time and the treatment then we note another significant relationship: the behavior of the low load subjects converged to the uncooperative Subgame Perfect prediction at a faster rate than did that of the high load subjects. However, when we perform the similar analysis, but with the provisional payoffs, we note that there was no differential convergence of game outcomes for the types.

One potential explanation for these two seemingly incongruent results is that low load subjects were better able to condition behavior on previous outcomes, and this agility offset the general trend towards the uncooperative outcomes. In particular, we found evidence that the low load subjects could, better than high load subjects, sustain cooperation when the level of cooperation in the previous period was high. We also found evidence that the low load subjects were more likely, than high load subjects, to play uncooperatively when there was an increase in the level of cooperation between the previous period and the period preceding that.

In other words, it seems that the low load subjects were better able to identify advantageous, temporary situations in which additional surplus could be captured.

So it seems that, while subjects in the high load treatments were more cooperative, and this would seem to imply higher provisional payoffs, this benefit of cooperation seems to have been offset by their reduced ability to condition actions on previous outcomes. The net result of these two effects, which work in opposite directions, results in no significant differences in either the provisional payoffs or the convergence rates of the provisional payoffs.

4 Conclusion

So are there brains in games? And if so, what else can we say? Our results suggest a qualified yes to the first question. 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.

Regarding the second question, the answer is somewhat delicate. We found that subjects within the low load treatment converged to the equilibrium prediction at a faster rate than did those under the high load. However, we found no differences in the convergence of the payoffs. To reconcile these two results, we note that the low load subjects were better able to condition their play on previous outcomes. This agility of the low load types seems to allow them to identify a temporary, advantageous situation and capture the available surplus. This agility seems to offset the effect on payoffs trend of playing uncooperatively.

There seem to be two ways to slice the results of the experiment. On the one hand, the reader who is not sympathetic to behavioral arguments, will point to the evidence of the convergence towards the Subgame Perfect behavior of both cognitive load treatments. Indeed, we found that subjects, even in the high load treatment, exhibited behavior which converged to that predicted by the theory. This seems to support the claim that subjects, even those with diminished cognitive resources, will eventually learn from their mistakes and therefore intelligence is ultimately of limited concern in strategic settings. Further, the lack of significance of the treatment dummy variable in the results involving choice or provisional payoffs, could also be used to support the claim that the cognitive resources available to the subject is of limited interest in a strategic setting.

On the other hand, the reader who is more sympathetic to behavioral arguments will note that the differences between the cognitive resources available to the subjects were directly related to the differences in the rate of the convergence to the equilibrium behavior. Indeed, we found that the subjects in the low load treatment converged to the equilibrium behavior at a faster rate than did the subjects in the high load treatment. Further, we found evidence that the low load subjects were more sensitive than high load subjects to previous outcomes. These results seem to offer support to the claim that the cognitive resources available to the subject are of interest in strategic settings. Despite the position of the reader, we hope that this experiment begins to clarify the role of cognitive resources in strategic settings.

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 turned their attention to nonequilibrium models which can account for errors made by subjects (McKelvey and Palfrey, 1995) or hierarchical levels of thinking (Camerer et. al., 2004; Costa-Gomes, et. al. 2001). It would seem natural to conclude that the intelligence of the subject would be related to either the errors committed or to the level of thinking employed by the subject. However, Georganas et. al. (2010) found that the mapping of measures of intelligence to the hierarchical level of thinking varies across games. While there could be other reasons for this negative result,[14] evidence of this kind is crucial in supporting existing nonequilibrium models or suggesting modifications to existing models. While the repeated nature of our present experiment does not allow a clean comparison to this 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.

[14] See Crawford et. al. (2010).

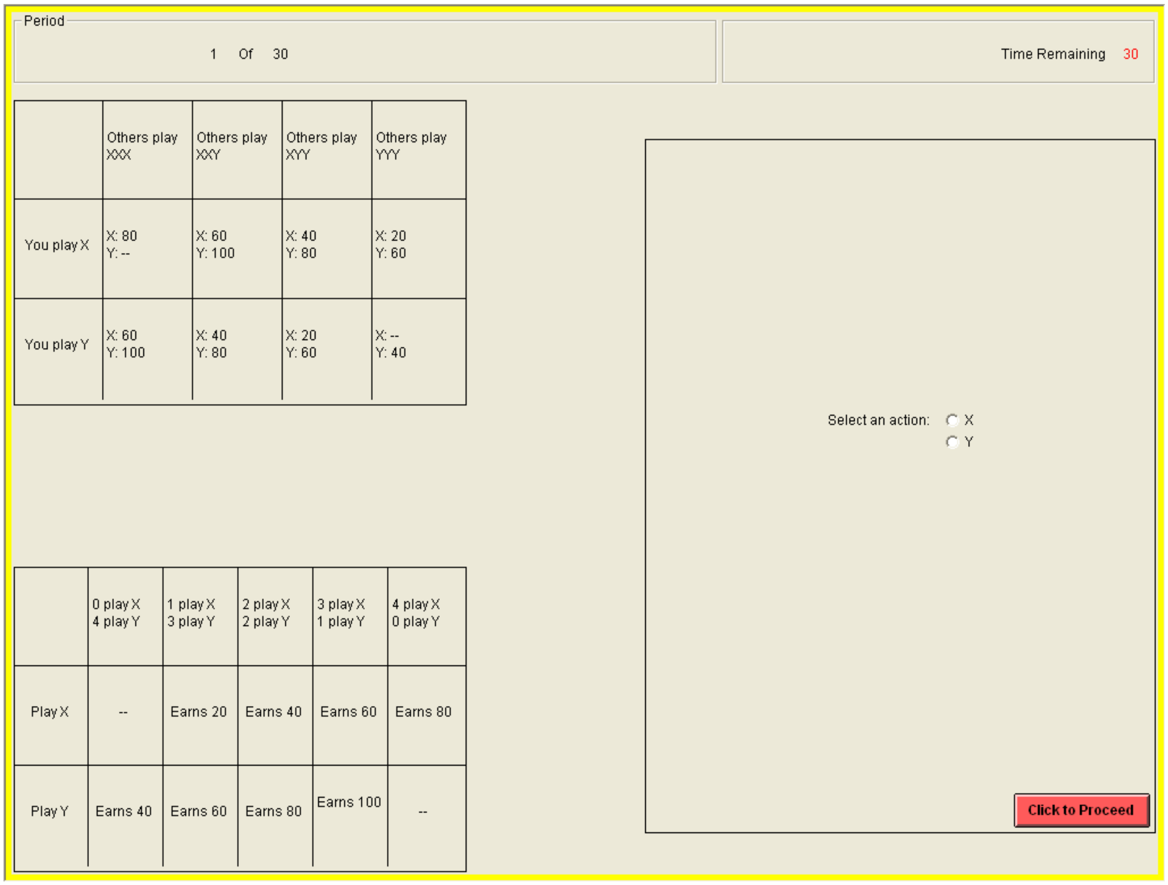
There remain several interesting and unanswered questions. For instance, it is unclear how the results would be affected by a game other than the multi-player prisoner's dilemma. For instance, it is unclear how the difference in behavior of the treatments would be affected by an increase (for instance, a public goods game or auction) or a decrease (for instance, a two-player prisoner's dilemma) in the computational difficulty of the game. We hope that future work will examine the role of the complexity of the game.

Another unanswered question relates to the significance of the incentives regarding the memorization task. While our cognitive load manipulation was successful, and we found no evidence of a relationship between choice and whether the memorization task was correct in that period, it is possible that the subjects exhibited an income effect. In other words, since payment was only made when the memorization task was correct, and the memorization task for the high load types was more difficult, it is possible that the subjects acted differently as a result of the financial incentives rather than the differential cognitive resources. We also hope that future work can address the affect of our incentives on our results.

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, only future work could test this conjecture.

5 Appendix

The screen during the game decision:



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