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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 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 condition their behavior on the outcomes of previous periods.

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. 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 of 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, 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

[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).

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 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 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 a 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 (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. 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

[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).

potential explanation for these two results, is our finding that low load subjects are better able to adjust their strategy in response to previous outcomes. As a result, these subjects are better able to identify temporary, advantageous 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

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., 2006), make more mistakes (Rydval, 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).

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 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 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 the subject 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 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.[6] 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 small literature on the relationship between intelligence and behavior in games.[7] For instance, Chen et al. (2009) measured the working memory of subjects and examined behavior in double auctions. The authors found some evidence that subjects with a higher working memory performed better. Devetag and Warglien (2003) found a relationship between the working memory capacity of a subject and the congruence of play to equilibrium behavior. Also 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.[8]

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 found that subjects

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

[7] Also see Bajo et al. (2011), Ballinger et al. (2011), Bayer and Renou (2011), Chen et al. (2011b), Jones (2011), Palacios-Huerta (2003), Putterman et al. (2011) and Rydval (2007).

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

with a higher measure of intelligence selected actions which are closer to the Nash Equilibrium of the beauty contest. On the other hand, 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] In other words, Jones found 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 would 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 very weak evidence of a difference between either the behavior or the game outcomes of the subjects in the high and low load treatments. However, we find that the behavior of the low load subjects converges 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.[10] 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 a problem, the response time will prove to be a useful measure of its efficacy. In other words, we use the response time as a measure of the cognitive resources devoted to deliberation in the game.

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

[10] For instance, Brañas-Garza and Miller (2008), Hogarth (1975), Piovesan and Wengström (2009), and Rubinstein (2007)

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.[11] 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 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 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 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 were homogenous, in that they contained only a single load treatment. However, there were 3 groups which were mixed in the sense

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

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 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 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 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. 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 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 game was played, we recorded the 2 instances of the 99999 output as 31 because 30 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 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.[12]

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. (2011) are the only examples of experiments with such material incentives. Cappelletti et al. (2011) 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. (2011), we provide no feedback regarding the accuracy of the memorization task. We make 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 between devoting cognitive resources for the memorization task and deliberation on 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 differences in the treatment 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

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

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 the present experimental 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 experimental design, there was little incentive for the subjects in the low load condition to quickly leave the stage where they are given the 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 following stage.

Finally, we study the four-player prisoner's dilemma[13] 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, 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

3.1 Manipulation checks and overview of the data

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

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

more impulsive ($p = 0.038$),[14] 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 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. 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 ($M = 1.19$, $SD = 2.20$), $t(1798) = 42.1$, $p < 0.001$.

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 tasks were preformed correctly. By comparison, we note that 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 below, we list the proportion of cooperation in the treatments by 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

Table 1 suggests that subjects across both treatments converged to the SPNE behavior. The table also suggests that the low load subjects converged to the SPNE behavior at a faster rate than the high load subjects. We now investigate whether these impressions are correct.

3.2 Differences in behavior

We now begin the analysis of the behavior of the subjects. We conduct this analysis with cooperation 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 dummy variable where 1 indicates that the subject was in the low load treatment and 0 otherwise. We use a dummy variable indicating whether the group was

[14] These are the results of a one-sided t-test between the high and low load subjects.

mixed and therefore contained subjects from both the high and low load treatments. Note that the regressions below, and throughout the paper, which account for the fixed-effects are specific to the subject rather than the group. While the groups are fixed throughout the experiment, there is subject-specific unobserved heterogeneity, which would remain constant throughout the experiment. As a result, we conduct subject specific and 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^{***}	-0.0236^{***}	-0.0267^{***}	-0.0267^{***}
	(0.00572)	(0.00627)	(0.00752)	(0.00801)	(0.00801)
Low Load	–	–	0.334^{*}	–	–
			(0.199)		
Period-Low Load Interaction	–	–	-0.0234^{**}	-0.0336^{***}	-0.0336^{***}
			(0.0116)	(0.0130)	(0.0130)
Mixed-Low Load Interaction	–	–	–	–	-3.3145
					(4.0291)
Fixed-effects?	No	Yes	No	Yes	Yes
-2 *Log L*	2355.44	2049.69	2351.34	2042.90	2042.90
$LR\ \chi^2$	35.19^{***}	340.94^{***}	39.28^{***}	347.73^{***}	347.73^{***}

We provide the coefficient estimates with standard errors in parentheses, where * indicates significance at 0.1, ** indicates significant 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 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 SPNE behavior. We also find weak evidence that subjects in the low load treatment are more generous than are subjects in the high load treatment. We find that the actions of the subjects in the high load treatment converged to the SPNE 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. We summarize the analysis of Table 2 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.

3.3 Differences in cognitive resources or differences in expected payments?

One potential explanation for the differences in the behavior of the subjects in the low load and high load treatments relates to differences in the expected payments across treatments. It is possible that the high load subjects expected to earn less than the low load subjects, and these differences in expectations, rather than the differences in the cognitive load, implied the differences in behavior. While it is not possible to determine the precise differences in the payment expectations, it is possible to look for evidence that the differences in behavior were motivated by this 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 the subject could use the 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 and the treatment.

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

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

The results of Table 3 suggest that the subjects attempted to correctly respond to the memorization task however, 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 the Table 2, with two departures. First, we include a variable Correct, which assumes a value of 1 if the memorization task in that period was performed correctly, and 0 otherwise. Second, we include the treatment dummy in regression (1). 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***	−0.0236***	−0.0267***	−0.0267***
	(0.00572)	(0.00627)	(0.00752)	(0.00801)	(0.00801)
Low Load	0.0267	–	0.376*	–	–
	(0.1031)		(0.201)		
Period-Low Load Interaction	–	–	−0.0235**	−0.0336***	−0.0336***
			(0.0116)	(0.0130)	(0.0130)
Mixed-Low Load Interaction	–	–	–	–	−3.393
					(4.035)
Correct	−0.223	−0.0637	−0.223	−0.0650	−0.0650
	(0.155)	(0.186)	(0.155)	(0.185)	(0.185)
Correct p-value	0.15	0.73	0.15	0.73	0.73
Fixed-effects?	No	Yes	No	Yes	Yes
-2 *Log L*	2353.39	2049.58	2349.28	2042.78	2042.78
$LR\ \chi^2$	34.42***	341.05***	41.35***	347.86***	347.86***

We provide the coefficient estimates with standard errors in parentheses, where * indicates significance at 0.1, ** indicates significant 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 the qualitative results summarized in Table 2 are not affected by the presence of the Correct variable. In other words, the results are not sensitive to our measure of the confidence that the subject would correctly perform the memorization task in that period. 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.

Finally, to address the possibility that differences in expectations of payment rather than differences in the cognitive load manipulation are responsible for our results, we again perform an analysis similar to that summarized in Table 2, but we exclude the observations where the subject incorrectly responded to the memorization task in that period. Since 820 of the 1020 memorization tasks in the high load treatment were performed correctly, and 766 of the 780 memorization tasks in the low load treatment were performed correctly, in the regressions below have 1586 observations. We summarize this analysis in Table 5.

Table 5 Logistic regressions of cooperation restricted to correct memorization tasks

	(1)	(2)	(3)	(4)	(5)
Period	−0.0365***	−0.0447***	−0.0269***	−0.0313***	−0.0313***
	(0.00615)	(0.00679)	(0.00849)	(0.00905)	(0.00905)
Low Load	–	–	0.3338	–	–
			(0.2110)		
Period-Low Load Interaction	–	–	−0.0199	−0.0302**	−0.0302**
			(0.0123)	(0.0138)	(0.0138)
Mixed-Low Load Interaction	–	–	–	–	−3.192
					(4.058)
Fixed-effects?	No	Yes	No	Yes	Yes
-2 *Log L*	2060.60	1790.24	2351.34	1785.39	1785.39
$LR\ \chi^2$	36.09***	306.44***	39.28***	311.29***	311.29***

We provide the coefficient estimates with standard errors in parentheses, where ** indicates significant at 0.05, and *** indicates significance at 0.01. Each regression has 1586 observations.

These results suggest that even when we restrict attention to the observations where the subject successfully performed the memorization task in that period, we still observe convergence to the SPNE behavior. Further, in regressions (4), and (5) we still find that the low load subjects converge to the SPNE behavior at a faster rate than the high load subjects. Whereas these features are shared by the analysis summarized in Table 2, we note that the outcome of regression (3) is different from that of regression (3) in Table 2. We observe that when we no longer include the observations associated with an incorrect response on the memorization task, neither the treatment variable nor the treatment-period interaction is significant. It is possible that this outcome is due to the fact that regression (3) does not account for the subject-specific fixed-effects. When we account for the subject-specific fixed-effects, as we do in regression (4), we observe that the interaction term is significant. In light of the analysis summarized in Tables 3, 4, and 5, we offer the following result.

Result 2 There is no evidence that subjects played the game when they were certain that they would not correctly perform the memorization task. Further, when we account for the outcome of the memorization task, we still find evidence of convergence to SPNE behavior across treatments and that low load subjects converge at a faster rate than the high load subjects.

3.4 Learning and response times

A 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 the action in the game. Recall that the experiment was designed in a manner which would reduce the incentive to alter the *optimal* decision time in the game stage because the subject would not necessarily proceed to the memorization task response stage. As such, we use the response time in the game stage as a measure the nature of the deliberation in the game. We run the following three regressions with the time remaining in the game stage as the dependent variable In other words, the size of our dependent variable is increasing in the speed of the decision. The results are summarized in Table 6.

Table 6 Time remaining at the decision in game stage			
	(1)	(2)	(3)
Period	0.247***	0.193***	0.193***
	(0.0148)	(0.0242)	(0.0196)
Low Load	–	−4.053***	–
		(0.651)	
Period-Low Load Interaction	–	0.126***	0.126***
		(0.0367)	(0.0297)
Fixed-effects?	Yes	No	Yes
R^2	0.43	0.12	0.44

Linear regressions with a dependent variable of time remaining in the game decision, where *** indicates significance at 0.01. Each regression has 1800 observations.

Table 6 provides evidence that there was a great deal of learning across periods. In all three specifications 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. Table 6 also suggests that the subjects in the low load treatment reflected on the decision longer than did the high load subjects. Finally, the result of regressions (2) and (3) suggest that the low load subjects exhibited faster learning across periods than did the subjects in the high load treatment, as demonstrated by the positive interaction term.

In our view, the results of Table 6 suggest an explanation for the results of Table 2. As previous research has indicated, a longer response time is associated with more strategic and less automatic reasoning. Therefore, the significant, positive estimates of the period coefficients in Table 6 suggest that the subjects are becoming familiar with the game. This seems to provide an explanation for the observation of the convergence to the SPNE behavior. The results of Table 6 also suggest that the low load subjects are becoming familiar with the game at a faster rate than are the high load subjects. Again this suggests an explanation for the result that the behavior of subjects in the low load treatment converged to the SPNE behavior at a faster rate than that of the high load subjects.

We also note that, unlike Table 2, Table 6 demonstrates that the treatment dummy is significant at 0.01. In particular, we observe that subjects in the high load treatment had a shorter response time 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. This provides an explanation for the observation that the high load subjects make their selection in the game at a faster rate. Regardless of the explanation of the significance of the treatment variable, this explanation would not explain that the results involving the period and the period-treatment interaction terms. We summarize the response time analysis with the following result.

Result 3: Throughout the experiment, subjects in both treatments exhibited decreasing response times in the game stage, however the response times of low load subjects decreased at a faster rate than the response times of high load subjects.

3.5 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. 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. These regressions are summarized in Table 7.

Table 7 Ordered multinomial logistic regressions of provisional payoffs

	(1)	(2)	(3)	(4)	(5)
Period	-0.0311^{***}	-0.0337^{***}	-0.0269^{***}	-0.0288^{***}	-0.0288^{***}
	(0.0050)	(0.00508)	(0.00662)	(0.0067)	(0.00671)
Low Load	–	–	0.301^{*}	–	–
			(0.1780)		
Period-Low Load Interaction	–	–	-0.00979	-0.0112	-0.0112
			(0.0100)	(0.0102)	(0.0102)
Mixed-Low Load Interaction	–	–	–	–	-8.349^{**}
					(3.460)
Fixed-effects?	No	Yes	No	Yes	Yes
-2 *Log L*	4921.75	4615.37	4917.88	4614.16	4614.16
$LR\ \chi^2$	38.60^{***}	344.99^{***}	42.47^{***}	346.19^{***}	346.19^{***}

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 was converging to the SPNE behavior. We also find that the low load dummy variable is significant only at the 0.10 level. Again, this is not surprising because we found a similar relationship between the low load dummy and behavior. However, we do not find evidence that the provisional payoffs of the low treatment subjects converged at a rate different than that of the high load subjects. In our view, this is surprising because the previous analysis suggested a strong difference in the convergence of the behavior of the subjects in the high and low treatments.

In regression (5), we find that the convergence result and the lack of significance in the difference in rates of convergence are not affected by the inclusion of the mixed-treatment interaction. Although we do not present this analysis in Table 7, we also note that these results qualitative 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 logits. We summarize this analysis with the following result.

Result 4 The provisional payoffs of the subjects converged to the provisional payoffs predicted by the SPNE outcome. However, there were not significant differences in the convergence of the provisional payoffs across the treatments.

3.6 Differences in ability to condition on previous outcomes

On the one hand, we found that the behavior in the low load treatment converged to the SPNE behavior faster than those in the high load treatments (see Tables 2 and 4). 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 (see Table 7). 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 additional agility offset the trend of playing uncooperatively.

In order to explore this explanation, we offer a model of cooperation which is possibly dependent on previous outcomes. In other words, we explore the extent to which subjects were able to condition play on the outcomes of previous periods. In the analysis described below, we assume that the subject considers features of these previous outcomes to be state variables upon 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 8.

Table 8 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	–	–	0.0947*	0.0825
-Lagged Change Interaction			(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 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 in regression (1). There we do not find evidence that lagged change in others playing cooperatively is related to cooperation. Finally, we do not observe a significant relationship between the sensitivity of the high load subjects to the change in cooperation and the sensitivity of the low load subjects.

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 a the 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 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 role of cognitive load in 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 9.

Table 9 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	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^{***}
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 suggests that none of the variables are related to cooperation for the high load subjects. 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 cooperation of the low load subjects at the 0.05 level. Further, the lagged change in others playing cooperatively is related to cooperation for the low load subjects at the 0.01 level. Together the results in Tables 8 and 9 suggest that the behavior of the low load subjects was more sensitive to previous outcomes than the behavior of the high load subjects. We summarize the analysis of Tables 8 and 9 with the following result.

Result 5: There is evidence that the low load subjects were better able to condition on previous outcomes than the high load subjects.

3.7 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 SPNE behavior. However, across all periods, we found only very weak evidence of a difference in the behavior of the high and low treatments. We note another significant relationship: the behavior of the low load subjects converged to the uncooperative SPNE prediction at a faster rate than that of the high load subjects. However, when we performed the similar analysis, but with the provisional payoffs, we note that there was no differential convergence of game outcomes across treatments.

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. 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 two previous periods. 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 converged to the selfish outcomes more slowly than the low load subjects, 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, resulted in no significant differences in the convergence rate 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 the behavior of low load subjects converged to the SPNE behavior at a faster rate than the high load subjects. However, we found no differences in the convergence of the provisional 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 subjects seems to have allowed them to identify advantageous, temporary situations and the ability to capture the available surplus.

There appear to be two ways to interpret the results of the experiment. On the one hand, the reader who is not sympathetic to behavioral arguments could point to the evidence of the convergence towards the SPNE behavior across 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 cooperation 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 could 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 SPNE 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 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,[15] 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 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.

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.

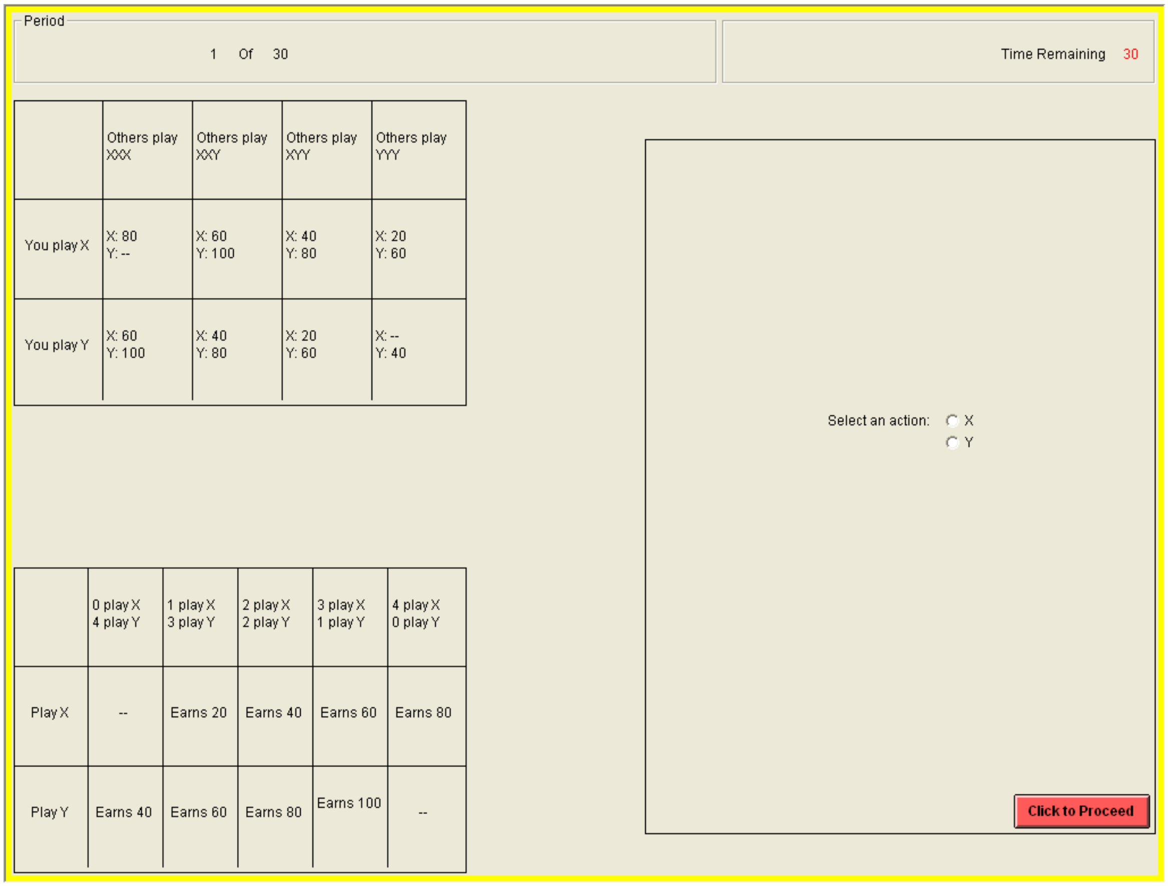
Another unanswered question relates to the significance of the incentives regarding the memorization task. While our cognitive load manipulation was successful, and we found no evidence of a relationship between cooperation and whether the memorization task was correct in that period, it is possible 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 subjects 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 effect of our incentives.

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 would be able to test this conjecture.

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

Appendix

The screen during the game decision:



	Others play XXX	Others play XXY	Others play XYY	Others play YYY
You play X	X: 80 Y: --	X: 60 Y: 100	X: 40 Y: 80	X: 20 Y: 60
You play Y	X: 60 Y: 100	X: 40 Y: 80	X: 20 Y: 60	X: -- Y: 40

	0 play X 4 play Y	1 play X 3 play Y	2 play X 2 play Y	3 play X 1 play Y	4 play X 0 play Y
Play X	--	Earns 20	Earns 40	Earns 60	Earns 80
Play Y	Earns 40	Earns 60	Earns 80	Earns 100	--

References

Bajo, María T., Brañas-Garza, Pablo, Georgantzís, Nikolaos, Morales, Julia, and Parravano, Melanie (2011): "Cognitive underpinnings of behavior in the Traveler's Dilemma: Treasures and Contradictions revisited," working paper University of Granada.

Ballinger, T. Parker, Hudson, Eric, Karkoviata, Leonie, and Wilcox, Nathaniel T. (2011): "Saving behavior and cognitive abilities," *Experimental Economics*, 14: 349–374.

Bayer, Ralph and Renou, Ludovic (2011): "Cognitive abilities and behavior in strategic-form games," working paper University of Leicester.

Béal, Sylvain (2010): "Perceptron versus automaton in the finitely repeated prisoner's dilemma," *Theory and Decision*, 69: 183–204.

Bednar, Jenna, Chen, Yan, Liu, Tracy Xiao, and Page, Scott (2012): "Behavioral Spillovers and Cognitive Load in Multiple Games: An Experimental Study," *Games and Economic Behavior*, 74(1): 12-31

Benjamin, Daniel, Brown, Sebastian, and Shapiro, Jesse (2006): "Who is 'Behavioral?' Cognitive Ability and Anomalous Preferences," working paper Harvard and Chicago.

Ben-Ner, Avner, Kong, Fanmin and Putterman, Louis (2004): "Share and share alike? Gender-pairing, personality, and cognitive ability as determinants of giving," *Journal of Economic Psychology*, 25: 581-589.

Brañas-Garza, Pablo and Miller, Luis (2008): "Instinctive Response in the Ultimatum Game," working paper Universidad de Granada and Oxford University.

Brandstätter, Hernann and Güth, Werner (2002): "Personality in Dictator and Ultimatum Games," *Central European Journal of Operations Research*, 10(3), 191-215.

Burks, Stephen V., Carpenter, Jeffrey P., Götte, Lorenz and Rustichini, Aldo (2009): "Cognitive Skills Explain Economic Preferences, Strategic Behavior, and Job Attachment," *Proceedings of the National Academy of Sciences*, 106(19): 7745–7750.

Burnham, Terence C., Cesarini, David, Johannesson, Magnus, Lichtenstein, Paul and Wallace, Björn (2009): "Higher cognitive ability is associated with lower entries in a p-beauty contest," *Journal of Economic Behavior and Organization*, 72: 171–175.

Camerer, Colin F., Ho, Teck-Hua, and Chong, Juin Kuan (2004): "A Cognitive Hierarchy Model of Games," *Quarterly Journal of Economics*, 119(3): 861–898.

Camerer, Colin F., and Hogarth, Robin M. (1999): " The effects of financial incentives in experiments: a review and capital-labor-production framework," *Journal of Risk and Uncertainty*, 19(1-3): 7–42.

Camerer, Colin F., Johnson, Eric J., Rymon, Talia and Sen, Sankar (1993) "Cognition and Framing in Sequential Bargaining for Gains and Losses." In *Frontiers of Game Theory*, ed. Ken Binmore, Alan Kirman, and Piero Tani. MIT Press, Cambridge, MA, 27–47.

Cappelletti, Dominique, Güth, Werner, and Ploner, Matteo (2011): "Being of two minds: Ultimatum offers under cognitive constraints," *Journal of Economic Psychology*, 32(6): 940–950.

Chen, Chia-Ching, Chiu, I-Ming, Smith, John, and Yamada, Tetsuji (2011a): "Too smart to be selfish? Measures of intelligence, social preferences, and consistency," working paper Rutgers University-Camden.

Chen, Chun-Ting, Huang, Chen-Ying and Wang, Joseph Tao-yi (2010): "A Window of Cognition: Eyetracking the Reasoning Process in Spatial Beauty Contest Games," working paper National Taiwan University.

Chen, Shu-Heng, Tai, Chung-Ching, and Yang, Lei-Xieng (2009): "Agent-Based Modeling of Cognitive Double Auction Market Experiments," working paper National Chengchi University.

Chen, Shu-Heng, Yang, Lee-Xieng, and Du, Ye-Rong (2011b): "Intelligence and Level-k Reasoning in Beauty-Contest Experiments: An Integrated Analysis," working paper National Chengchi University.

Coricelli, Giorgio and Nagel, Rosemarie (2009): "Neural correlates of depth of strategic reasoning in medial prefrontal cortex," *Proceeings of the National Acadamy of Science*, 106 (23), 9163–9168.

Cornelissen, Gert , Dewitte, Siegfried, Warlop, Luk, and Yzerbyt, Vincent (2007): "Whatever people say I am, that's what I am: Social labeling as a social marketing tool," *International Journal of Research in Marketing*, 24: 278–288.

Cornelissen, Gert, Dewitte, Siegfried, and Warlop, Luk (2011): "Are Social Value Orientations expressed automatically? Decision making in the dictator game," *Personality and Social Psychology Bulletin*, 37(8): 1080–1090.

Costa-Gomes, Miguel A., Crawford, Vincent P. and Broseta, Bruno (2001): "Cognition and Behavior in Normal-Form Games: An Experimental Study," *Econometrica*, 69(5): 1193–1235.

Costa-Gomes, Miguel A., and Crawford, Vincent P. (2006): "Cognition and Behavior in Two-Person Guessing Games: An Experimental Study," *American Economic Review*, 96(5): 1737–1768.

Cowan, Nelson (2001): "The magical number 4 in short-term memory: A reconsideration of mental storage capacity," *Behavioral and Brain Sciences*, 24(1): 87–185.

Crawford, Vincent P. (2008): "Look-ups as the Windows of the Strategic Soul." In *The Foundations of Positive and Normative Economics: A Handbook*, ed. Andrew Caplin and Andrew Schotter. Oxford University Press: Oxford, 249–280.

Crawford, Vincent P., Costa-Gomes, Miguel A. and Iriberri, Nagore (2010): "Strategic Thinking," working paper UCSD.

Devetag, Giovanna and Warglien, Massimo (2003): "Games and phone numbers: Do short-term memory bounds affect strategic behavior?" *Journal of Economic Psychology*, 24: 189–202.

Dewitte, Siegfried, Pandelaere, Mario, Briers, Barbara, and Warlop, Luk (2005): "Cognitive load has negative after effects on consumer decision making," working paper Katholieke Universiteit Leuven, Belgium.

Dohmen, Thomas, Falk, Armin, Huffman, David, and Sunde, Uwe (2010): "Are Risk Aversion and Impatience Related to Cognitive Ability?" *American Economic Review*, 100(3): 1238–1260.

Fischbacher, Urs (2007): "z-Tree: Zurich Toolbox for Ready-made Economic Experiments," *Experimental Economics*, 10(2): 171–178.

Frederick, Shane (2005): "Cognitive Reflection and Decision Making," *Journal of Economic Perspectives*, 19(4): 25–42.

Georganas, Sotiris, Healy, Paul J., and Weber, Roberto A. (2010): "On the Persistence of Strategic Sophistication," working paper Ohio State University.

Gilbert, Daniel T., Pelham, Brett W., and Krull, Douglas S. (1988): "On Cognitive Busyness: When Person Perceivers Meet Persons Perceived," *Journal of Personality and Social Psychology*, 54 (5): 733–740.

Hauge, Karen Evelyn, Brekke, Kjell Arne, Johansson, Lars-Olof, Johansson-Stenman, Olof, and Svedsäter, Henrik (2009): "Are Social Preferences Skin Deep? Dictators under Cognitive Load," working paper University of Gothenburg.

Hinson, John M., Jameson, Tina L., and Whitney, Paul (2002): "Somatic markers, working memory, and decision making," *Cognitive, Affective, and Behavioral Neuroscience*, 2 (4): 341–353.

Hinson, John M., Jameson, Tina L., and Whitney, Paul (2003): "Impulsive Decision Making and Working Memory," *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 29(2): 298–306.

Hogarth, Robin M. (1975): "Decision time as a function of task complexity," In Dirk Wendt and Charles Vlek (Eds.), *Utility, probability, and human decision making*, D. Reidel Publishing: Boston, 321–338.

Johnson, Eric J., Camerer, Colin, Sen, Sankar, and Rymon, Talia (2002): "Detecting Failures of Backward Induction Monitoring Information Search in Sequential Bargaining," *Journal of Economic Theory*, 104: 16–47.

Jones, Garett (2008): "Are smarter groups more cooperative? Evidence from prisoner's dilemma experiments, 1959-2003," *Journal of Economic Behavior and Organization*, 68: 489–497.

Jones, Matthew T. (2011): "Strategic Complexity and Cooperation: An Experimental Study," working paper, Ohio State University.

Komorita, S. S., Sweeney, James, and Kravitz, David A. (1980): "Cooperative Choice in the N-Person Dilemma Situation," *Journal of Personality and Social Psychology*, 38 (3): 504–516.

Miller, George (1956): "The magical number seven, plus or minus two: Some limits on our capacity for processing information," *Psychological Review*, 63 (2): 343–355.

Millet, Kobe and Dewitte, Siegfried (2007): "Altruistic Behavior as a Costly Signal of General Intelligence," *Journal of Research in Personality*, 41, 316-326.

Nagel, Rosemarie (1995): "Unraveling in Guessing Games: An Experimental Study," *American Economic Review*, 85(5): 1313–1326.

Neyman, Abraham (1985): "Bounded complexity justifies the cooperation in the finitely repeated prisoner's dilemma," *Economic Letters*, 19, 227–229.

Neyman, Abraham (1998): "Finitely repeated games with finite automata," *Mathematics of Operations Research*, 23, 513–552.

Palacios-Huerta, Ignacio (2003) "Learning to Open Monty Hall's Doors," *Experimental Economics*, 6(3): 235–251.

Piovesan, Marco and Wengström, Erik (2009): "Fast or Fair? A Study of Response Times," *Economics Letters*, 105: 193–196.

Putterman, Louis, Tyran, Jean-Robert and Kamei, Kenju (2011): "Public goods and voting on formal sanction schemes," *Journal of Public Economics*, 95: 1213–1222.

Roch, Sylvia G., Lane, John A. S., Samuelson, Charles D., Allison, Scott T. and Dent, Jennifer L. (2000): "Cognitive Load and the Equality Heuristic: A Two-Stage Model of Resource Overconsumption in Small Groups," *Organizational Behavior and Human Decision Processes*, 83(2): 185–212.

Rubinstein, Ariel (2007): "Instinctive and Cognitive Reasoning: A Study of Response Times," *Economic Journal*, 117: 1243–1259.

Rydval, Ondrej (2007): "Financial Incentives and Cognitive Abilities: Evidence from a Forecasting Task with Varying Cognitive Load," working paper Max Planck Institute.

Rydval, Ondrej and Ortmann, Andreas (2004): "How financial incentives and cognitive abilities affect task performance in laboratory settings: an illustration," *Economics Letters*, 85: 315–320.

Savikhina, Anya and Sheremeta, Roman M. (2009): "Simultaneous Decision-Making in Competitive and Cooperative Environments," working paper Purdue University and Chapman University.

Shiv, Baba and Fedorikhin, Alexander (1999): "Heart and Mind in Conflict: The Interplay of Affect and Cognition in Consumer Decision Making," *Journal of Consumer Research*, 26(3): 278–292.

Stahl, Dale and Wilson, Paul (1994): "Experimental Evidence on Players' Models of Other Players," *Journal of Economic Behavior and Organization*, 25: 309–327.

Stahl, Dale, and Wilson, Paul (1995): "On Players' Models of Other Players: Theory and Experimental Evidence," *Games and Economic Behavior*, 10: 218–254.

Swann, William B., Hixon, Gregory, Stein-Seroussi, Alan, and Gilbert, Daniel T. (1990): "The Fleeting Gleam of Praise: Cognitive Processes Underlying Behavioral Reactions to Self-Relevant Feedback," *Journal of Personality and Social Psychology*, 59 (1): 17–26.

Van den Bos, Kees , Peters, Susanne L., Bobocel, D. Ramona, and Ybema, Jan Fekke (2006): "On preferences and doing the right thing: Satisfaction with advantageous inequity when cognitive processing is limited," *Journal of Experimental Social Psychology*, 42: 273–289.

Wang, Joseph Tao-yi, Spezio, Michael and Camerer, Colin F. (2010): "Pinocchio's Pupil: Using Eyetracking and Pupil Dilation To Understand Truth Telling and Deception in Sender-Receiver Games," *American Economic Review*, 100(3), 984–1007.

Ward, Andrew and Mann, Traci (2000): "Don't Mind If I Do: Disinhibited Eating Under Cognitive Load," *Journal of Personality and Social Psychology*, 78 (4): 753–763.