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Cognitive load and strategic sophistication☆

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ABSTRACT

We study the relationship between the cognitive load manipulation and strategic sophistication. The cognitive load manipulation is designed to reduce the subject's cognitive resources that are available for deliberation on a choice. In our experiment, subjects are placed under a high cognitive load (given a difficult number to remember) or a low cognitive load (given a number that is not difficult to remember). Subsequently, the subjects play a one-shot game then they are asked to recall the number. This procedure is repeated for various games. We find that the relationship between cognitive load and strategic sophistication is not persistent across classes of games. This lack of persistence is consistent with recent findings in the literature. We also find that the relationship between cognitive load and actions is different from the relationship between cognitive load and beliefs. This suggests that actions and beliefs may not be as closely related as standard game theory would predict.

1. Introduction

Models of strategic sophistication have greatly improved our understanding of play in games.[1] These models posit that subjects exhibit heterogenous sophistication in their thinking of the game. An open question relates to the origin of these strategic levels and whether they arise from a specific trait of the subjects. A natural candidate for the source of the strategic levels is the measured cognitive ability of the subject. This has prompted researchers to investigate the relationship between measured cognitive ability and strategic sophistication.[2]

However, one difficulty in employing measures of cognitive ability is that subjects with different cognitive ability are possibly also different in other ways. As such, it might not be possible to distinguish between an alternate hypothesis that

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[1] For instance, Stahl and Wilson (1994, 1995), Nagel (1995), Costa-Gomes et al. (2001), Costa-Gomes and Crawford (2006), and Camerer et al. (2004). See Crawford et al. (2013) for an updated overview of the field.

[2] For instance, see Bayer and Renou (2012), Burnham et al. (2009), Brañas-Garza et al. (2011), Carpenter et al. (2013), Devetag and Warglien (2003), Georganas et al. (2015), and Gill and Prowse (2015).

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an unobserved characteristic is responsible for the level of strategic sophistication, and cognitive ability is merely correlated with this characteristic. Here, rather than measure cognitive ability, we manipulate the cognitive resources available to the subject via cognitive load. Cognitive load experiments often direct subjects to make a decision in one domain while simultaneously manipulating the cognitive resources available to reflect on the decision.

The cognitive load manipulation is designed to occupy a portion of the working memory capacity of the subject. Working memory can be conceptualized as the cognitive resources available to temporarily store information so that it can be used in decision making. Therefore, working memory is instrumental in the execution of deliberative thought.[3] Several studies have found that measures of cognitive ability are positively related to measures of working memory capacity.[4] Further, reducing the available working memory of a subject via cognitive load, reduces the cognitive resources available for deliberation, and can be regarded as similar to the condition of having a diminished cognitive ability. Additionally, given the within-subject design of our experiment, we are able to observe the behavior of each of the subjects in different cognitive load treatments. As a consequence, our results are not possibly driven by unobserved characteristics that are only related to cognitive ability.[5]

We tested whether the cognitive load manipulation would produce uniformly less strategically sophisticated behavior. However, we find that the relationship between cognitive load and strategic sophistication is not persistent across classes of games. In our experiment, we directed subjects to play various one-shot games while under a cognitive load. In particular, they played ten 3×3 games, a variation of the 11–20 game (Arad and Rubinstein, 2012), and a variation of the beauty contest game (Nagel, 1995). We note that our version of the 11–20 game is relatively simple, the beauty contest is relatively complicated, and the 3×3 games have various levels of complexity.

The subjects played these games under either a low or a high cognitive load. Subjects in the low load were directed to commit a three digit binary number to memory and subjects under a high load were directed to commit a nine digit binary number to memory. Subsequently, the subjects were asked to recall the number. Further, in some treatments subjects were also informed about the load of their opponent.

The cognitive load manipulation is consistent with two effects. First, subjects under a high cognitive load can have difficulty making the computations associated with optimal play. Second, subjects under a high load are aware of the first effect and can decide to devote additional cognitive effort in order to mitigate this disadvantage. We find that the net result of these two opposing effects depends on the strategic setting and is not persistent across different classes of games.

The first effect dominates the second effect when, in the relatively complicated beauty contest game, the subjects under a high load selected less strategic actions. We also find that in relatively simple 3×3 games, subjects under a high load were less likely to play their Nash equilibrium action than were subjects under a low load. These results identify settings in which subjects under a high load were less strategically sophisticated than subjects under a low load.

On the other hand, the second effect dominates the first effect, where subjects under a high load selected a more strategic response in the relatively uncomplicated 11–20 game. Additionally, in the beauty contest game, when subjects under a high load were reminded of the distribution of the cognitive load of their opponents they were more sophisticated than subjects under a high load who were not reminded. However, subjects under a low load were not affected by the reminder. These results identify settings in which subjects under a high load were more strategically sophisticated than subjects under a low load.

Overall, we find a relationship between available cognitive resources and strategic sophistication that is not persistent across different classes of games. In order to better understand this lack of persistence, we also analyze beliefs in the 3×3 games. We find that the relationship between cognitive load and strategic actions is different from the relationship between cognitive load and strategic beliefs. This suggests that actions and beliefs are less closely related than predicted by standard game theory.

This lack of the persistence is also consistent with the recent findings of Georganas et al. (2015). These authors find evidence that strategic sophistication can be largely persistent within a class of games but is not persistent across classes of games. Our findings compliment this result in that we observe that the implications of available cognitive resources on strategic behavior are not persistent across classes of games.

1.1. Related literature

The economics literature increasingly regards the brain as an object worthy of study in that, subject to its limitations and heterogeneity across subjects, it is the source of economic behavior. This line of inquiry has investigated topics ranging from the effects of sleep on strategic behavior (Dickinson and McElroy, 2010, 2012), to optimal search patterns (Sanjurjo, 2014, 2015), to neurological studies of the brain during choice (Coricelli and Nagel, 2009, 2012), to novel elicitation methods designed to measure the reasoning of subjects (Agranov et al., 2015; Burchardi and Penczynski, 2014; Chen et al., 2013b;

[3] See Alloway and Alloway (2013).

[4] For instance, see Conway et al. (2003), Kane et al. (2005), Oberauer et al. (2005), and Süßet al. (2002). See Burgess et al. (2011) and Cole et al. (2012) for recent advances in understanding the neurological basis of this relationship.

[5] We note that research finds that the cognitive load manipulation is more effective on subjects with a higher measure of cognitive ability (Carpenter et al., 2013). However we do not find evidence of this in our setting. In every regression involving our measure of cognitive ability (self-reported grade point average) we also run unreported specifications where we also include the interaction with the grade point average and the cognitive load. In only a single specification do we find a significant interaction.

Crawford, 2008). In particular, there is a growing literature that investigates the relationship between measured cognitive ability and economic preferences[6] and the relationship between measured cognitive ability and behavior in games.[7] To the extent that subjects under a high cognitive load are similar to the condition of having a low cognitive ability, our results provide evidence on the relationship between cognitive ability and strategic sophistication.

There is an extensive literature on the cognitive load manipulation in nonstrategic settings. The research finds that subjects under a high cognitive load are more impulsive and less analytical (Hinson et al., 2003), are more risk averse (Whitney et al., 2008; Benjamin et al., 2013), are more impatient (Benjamin et al., 2013), make more mistakes on a forecasting task (Rydval, 2011), exhibit less self control (Shiv and Fedorikhin, 1999; Ward and Mann, 2000; Mann and Ward, 2007), fail to process available information (Gilbert et al., 1988; Swann et al., 1990), are more susceptible to anchoring effects (Epley and Gilovich, 2006), perform worse on gambling tasks (Hinson et al., 2002), perform worse on visual judgment tasks (Morey and Cowan, 2004; Allen et al., 2006; Morey and Bieler, 2013; Zokaei et al., 2014; Allred et al., 2015), make different choices in allocation decisions (Cornelissen et al., 2011; Schulz et al., 2014),[8] have different evaluations of the fairness of outcomes (Van den Bos et al., 2006), have more difficulty telling a lie (van't Veer et al., 2014), and exhibit choices that are more sensitive to the visual salience of an object (Milosavljevic et al., 2012).[9] This literature finds that the behavior under a cognitive load is consistent with the condition that the subjects have fewer cognitive resources available for deliberative thought.

On the other hand, there are not many studies of strategic behavior that employ the cognitive load manipulation. To our knowledge, Buckert et al. (2013), Cappelletti et al. (2011), Carpenter et al. (2013), Duffy et al. (2016), Duffy and Smith (2014), Milinski and Wedekind (1998), Roch et al. (2000), and Samson and Kostyszyn (2015) are the only such examples. We note that only Carpenter et al. is designed to investigate models of strategic sophistication in one-shot games. For instance, Buckert et al. (2013) find that high load subjects in a repeated Cournout oligopoly game were more likely to employ the imitation heuristic. Milinski and Wedekind (1998) find that high load subjects in the repeated prisoner's dilemma game employed less complicated strategies than low load subjects. Duffy and Smith (2014) find that low load subjects in a finitely repeated multi-player prisoner's dilemma game exhibited more defection near the end of play and they were better able to condition their strategy on previous outcomes. However, these studies do not lend themselves to the study of strategic sophistication, as the games are repeated and the subjects receive feedback.

In contrast, Carpenter et al. (2013) induced a differential cognitive load in subjects then observed their strategic sophistication. The subjects played a sequential game that can be solved by backwards induction. The subjects were also asked to provide both actions and beliefs in the beauty contest game. The authors find that high load subjects were less strategic in that they were less able to perform backwards induction. Additionally, the authors find that high load subjects believed that their beauty contest opponents would select a higher number and the authors observed a larger deviation from the best response to these beliefs. Our most comparable result is that we find that subjects under a high load were less strategic in that they selected a higher number in the beauty contest. While our beauty contest results coincide with those of Carpenter et al., we also find that, depending on the type of the game, subjects under a high load can be considered to be more sophisticated than subjects under a low load.

We also note that there are methodological differences between Carpenter et al. and our paper. First, Carpenter et al. employed a between-subjects design, whereby subjects were exclusively in a single cognitive load treatment. This design introduces possible differences in payments across treatments since the memorization task was incentivized. By contrast, we employ a within-subjects design, whereby each subject played some games under a high load and other games under a low load. Therefore, the differences that we observe are not possibly driven by differences in the payments across the cognitive load treatments.

2. Method

A total of 308 subjects participated in the experiment. The subjects were drawn from the experimental economics subject pool at Rutgers University-New Brunswick and the sessions were conducted in the Wachtler Experimental Economics Laboratory. The experiment was programmed and conducted with the software z-Tree (Fischbacher, 2007).[10] Sessions lasted from 60 to 75 min.

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[6] See Andersson et al. (2015), Beauchamp et al. (2011), Benjamin et al. (2013), Ben-Ner et al. (2004), Brañas-Garza et al. (2008), Brandstätter and Güth (2002), Burks et al. (2009), Chen et al. (2013a,b), Cokely and Kelley (2009), Dohmen et al. (2010), Frederick (2005), Millet and Dewitte (2007), Oechssler et al. (2009), and Ponti and Rodriguez-Lara (2015). See Arruñada et al. (2015) and Dittrich and Leipold (2014) for the relationship between measures of strategic behavior and social preferences.

[7] See Ballinger et al. (2011), Baghestanian and Frey (2015), Bayer and Renou (2012), Brañas-Garza et al. (2012), Brañas-Garza et al. (2011), Carpenter et al. (2013), Chen et al. (2014, 2013b), Fehr and Huck (2015), Gill and Prowse (2015), Grimm and Mengel (2012), Hanaki et al. (2015), Jones (2014, 2008), Kiss et al. (2015), Palacios-Huerta (2003), Proto et al. (2014), Putterman et al. (2011), Rydval (2011), Rydval and Ortmann (2004), and Schnusenberg and Gallo (2011).

[8] Although Hauge et al. (2015) does not find an effect.

[9] Deck and Jahedi (2015) study several effects at a time and find that subjects under a cognitive load are less patient, more risk averse, perform worse on arithmetic tasks, and are more prone to anchoring effects.

[10] The z-Tree code is available from the corresponding author upon request.

2.1. Specification of the games

We directed subjects to play ten 3 × 3 games, an adaptation of the 11–20 game, and an adaptation of the beauty contest game. The subjects were not given feedback about the outcomes of the games. The subjects were told that they would be randomly and anonymously rematched in each of the games.

First, we directed subjects to play 10 simultaneous action 3 × 3 games. These games are simplified versions of games used by Costa-Gomes and Weizsacker (2008), Rey-Biel (2009), and Bayer and Renou (2012). In these games, each subject was matched with another subject and both made a selection among three possible actions. In addition to selecting an action, we also elicited the point beliefs[11] of the subjects about the action of the other player.

Each of the 3 × 3 games has an original version (labeled A) and a transposed version of the original game (labeled B). In other words, the A and B versions are strategically similar but the roles have been reversed. Fig. 1 illustrates the ten 3 × 3 games. From the perspective of the games as specified in Fig. 1, subjects played all 10 games as either a row or a column player. Therefore, each subject played both roles in each of the 5 strategically similar games. We note that the game was always presented so that the subject was the row player and the opponent was the column player. As a result, every player selected among actions labeled Top, Middle, and Bottom, and selected beliefs about the action of the opponent that were labeled Left, Center, and Right. We employed 4 different orderings of these 10 games. Throughout the experiment, 10 points were equivalent to $3.50. If the subject's beliefs of the opponent's action matched the opponent's action, the subject was rewarded with 4 points.[12]

We also used a variant of the 11–20 game (Arad and Rubinstein, 2012). Subjects were randomly matched with another subject and selected an integer between 1 and 10. The subjects received the amount selected, however, the subject received a bonus of 10 points if they selected a number exactly one digit lower than their opponent. Hereafter, we refer to this game as the *1–10* game.

Finally, we employed a version of the beauty contest game (Nagel, 1995). Each subject selected a half-integer between 0 and 10. The subject who selected the number closest to 2/3 of the average in the session received $30.

2.2. Memorization task

Before play in every game, the subjects were given up to 15 s to commit a number to memory. The subjects were told that after the game, they would be asked for the number. These numbers were always composed of a string of either 0 or 1, and the first digit was always 1. In the high load treatment, we required the memorization of a 9 digit string, for example: 101110001. In the low load treatment, we required the memorization of a 3 digit string, for example: 110. We employed a within-subject design, whereby the subjects faced an alternating load of high and low. Half of the subjects were given the high load first and half were given the low load first. A new number was randomly given in each of the games. The subjects were not given feedback about the results of the memorization task.

2.3. Controlling for beliefs

Of the 308 subjects, 144 were given information about the load of their opponent in the 3 × 3 games and the 1–10 game.[13] This took the form of a screen that stated that the other player "will have to remember a: Big (Small) Number." Additionally, during the decision in the 3 × 3 games, the subjects were also reminded of the load of their opponent.[14] In order to give subjects a consistent sequence of stimuli, prior to the beauty contest game, these subjects were shown a screen that stated that roughly 50% of the other subjects were given a big number and roughly 50% were given a small number. In order to minimize the effect of the load on processing this information, the subjects were informed of the load of their opponent prior to the memorization task.

2.4. Experimental timeline and details

Before the incentivized portion of the experiment, we provided four unincentivized tasks: two practice memorization tasks and two simple addition tasks. First, the subjects were given two unincentivized practice rounds with the memorization task, one with a large number and one with a small number. Then, in order to illustrate the extent to which the loads can affect the ability to make basic computations, we provided a memorization number, then we directed the subjects to sum two randomly selected integers between 11 and 40, then we asked for the memorization number. The subjects performed this addition task under both a low and a high cognitive load.

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[11] Here we measure beliefs by allowing the subject to select only a single possible action of the opponent. There exist more complicated procedures. For instance, one could elicit a distribution of the likelihood of the possible actions of the opponent.

[12] See Appendix A or a screenshot from the 3 × 3 games.

[13] For studies that have controlled for or manipulated beliefs, see Agranov et al. (2012), Alaoui and Penta (2015), de Sousa et al. (2013), Georganas et al. (2015), Palacios-Huerta and Volij (2009), and Slonim (2005).

[14] See Appendix A for a screen shot.

Games 1A and Game 1B: both players have 2 dominated strategies. The game is adapted from Game 1 of Bayer and Renou (2012).

Game 1A

	Left	Center	Right
Top	8, 4	**5, 7**	3, 6
Middle	6, 8	4, 9	1, 2
Bottom	7, 1	2, 5	2, 4

Game 1B

	Left	Center	Right
Top	2, 8	3, 1	8, 7
Middle	**6, 6**	4, 3	9, 5
Bottom	5, 4	1, 1	7, 3

Games 2A and 2B: one player has a dominated strategy and the other player has two. The game is adapted from Game 3 of Bayer and Renou (2012).

Game 2A

	Left	Center	Right
Top	8, 8	3, 5	1, 9
Middle	9, 2	5, 3	**6, 4**
Bottom	4, 1	7, 6	2, 8

Game 2B

	Left	Center	Right
Top	4, 5	6, 3	7, 7
Middle	3, 9	9, 8	2, 4
Bottom	**5, 6**	10, 1	9, 2

Games 3A and 3B: one player has two dominated strategies, the other player does not have any dominated strategies. The game is adapted from Game VS1R of Rey-Biel (2009).

Game 3A

	Left	Center	Right
Top	1, 9	2, 6	4, 3
Middle	4, 4	5, 4	5, 4
Bottom	7, 3	7, 5	**6, 8**

Game 3B

	Left	Center	Right
Top	10, 2	2, 10	7, 11
Middle	7, 3	6, 4	7, 10
Bottom	6, 6	1, 7	**9, 8**

Games 4A and 4B: one player has one dominated strategy, other player does not have a dominated strategy. The game, adapted from Game VS2R of Rey-Biel (2009), is dominance solvable.

Game 4A

	Left	Center	Right
Top	6, 6	4, 8	**4, 9**
Middle	4, 8	11, 3	3, 5
Bottom	1, 10	10, 6	3, 8

Game 4B

	Left	Center	Right
Top	11, 1	1, 8	7, 5
Middle	4, 8	4, 8	1, 11
Bottom	6, 5	**5, 7**	2, 5

Games 5A and 5B: neither player has a dominated strategy. The game is adapted from Game VSNDR of Rey-Biel (2009).

Game 5A

	Left	Center	Right
Top	8, 6	2, 6	1, 11
Middle	4, 6	**7, 6**	3, 6
Bottom	2, 7	2, 5	4, 4

Game 5B

	Left	Center	Right
Top	3, 10	5, 5	3, 9
Middle	4, 9	2, 9	**4, 9**
Bottom	9, 5	3, 8	2, 7

Fig. 1. Specification of the 3 × 3 games. The payoffs in the Nash Equilibria are denoted in bold.

Subsequently, we provided the subjects with a basic understanding of 3 × 3 games.[15] We then directed the subjects to play the 3 × 3 games under a differential cognitive load. Before each of these games, we gave the subjects the memorization number, then we presented the game, then we asked for the memorization number. The instructions stated that, should the subject perform X of the 10 memorization tasks correctly in the 3 × 3 games then the computer would randomly select the maximum of either 0 or $X - 7$ outcomes of the 3 × 3 games for payment. In other words, if the subject correctly performed 10 of the 10 memorization tasks then the subject would be paid for 3 randomly selected games. If the subject correctly performed 9 memorization tasks then the subject would be paid for 2 games. If the subject correctly performed 8 memorization tasks then the subject would be paid for 1 game. If the subject correctly performed 7 or fewer memorization tasks then the subject would not receive payment for these games.

[15] These instructions are available from the corresponding author upon request.

Between each of the ten 3 × 3 games, the subjects were forced to take a 20 s rest. During this rest period the subjects were not able affect the screen that read, “Rest!!! Because a new game will start soon.”

After the 3 × 3 games, the subjects were directed to play the 1–10 game and the beauty contest game, under the alternating cognitive load that continued from the previous stage. The subjects were told that they would be paid the amount of the 1–10 game and the beauty contest game only if the memorization task was performed correctly for both of these games. Note that we did not load the subjects when they were reading the instructions for the 1–10 game and the beauty contest game.

After the beauty contest memorization task was completed, the subjects were directed to indicate their gender, whether they are an economics major, whether they have taken a game theory course, an optional estimate of their grade point average[16] (GPA), and a rating of the difficulty in recalling the large and the small memorization numbers. These difficulty ratings were elicited on a scale of 1 (“Very Difficult”) to 7 (“Not Very Difficult”). Subsequently, the subjects were told their amount earned and they were paid in cash. The subjects earned an average of $17.67 (*SD* = 6.11).

2.5. Discussion of the experimental design

First, we employ a within-subject design, rather than a between-subject design. This is notable because research suggests that the effects of the cognitive load manipulation can be lasting (Dewitte et al., 2005). In order to mitigate the effects of the load of previous rounds, we employed a mandatory rest-period between games. While we cannot say whether our subjects exhibited any cognitive load carry-over effects from the load in previous periods, this possibility does not threaten our results because this would only serve to diminish the differences between the cognitive load treatments. Our results would only be strengthened if we could completely remove any carry-over effects. Second, unlike Duffy and Smith (2014), which employed a memorization number composed of digits ranging from 0 to 9, we restrict attention to numbers composed exclusively of either 0 or 1. This design was intended to mitigate the interaction between the game payoff numbers and the memorization task numbers.

While we could observe that subjects were not able to employ any obvious memorization aids (cell phones, writing the number on paper, etc.) we cannot say with certainty that no subject used a memorization aid. For instance, with an appropriate positioning of the free body parts (feet, legs, elbows, wrists, and fingers on left hand) one could possibly devise a code to aid memorization.[17] In our view, this possibility is not as advantageous as it first appears. This is because the subject must also remember the code, and this will occupy cognitive resources. Further, similar to the possibly of an insufficient rest period, our results would only be strengthened if we could exclude subjects who possibly employed a memorization aid.

Additionally, we designed the experiment so that the responses to the games were as simple as possible. For instance, in the 3 × 3 games we elicited the point beliefs of the action of the opponent rather than more sophisticated measures of beliefs. This procedure has a drawback that our beliefs measure is coarse. On the other hand, the task is sufficiently simple so that the memorization task was not likely to affect the ability to comply with the elicitation procedure. Additionally, we elicited responses to the beauty contest, which were the 21 half-integers between 0 and 10 rather than, as is more standard, the integers or real numbers between 0 and 100. More generally, we designed the experiment so that every response in the games took a different format than that required for the memorization task. In the 3 × 3 games, the 1–10 game, and the beauty contest game, the responses involved clicking on the corresponding button, whereas the memorization task required entering a sequence of digits. Additionally, we did not load the subjects during the instructions of the 1–10 game and the beauty contest game because this could reduce the comprehension of the instructions.[18]

We employed a simplified version of the 3 × 3 games originally used by Costa-Gomes and Weizsacker (2008), Rey-Biel (2009), and Bayer and Renou (2012). The original games have integer payoffs that range from 10 to 98. We employed a simplified version where payoffs are integers that range from 1 to 11. This design was intended to reduce the computational difficulty in deciding on an action.

We now discuss the equilibrium details of the games. The 3 × 3 games each have a single pure strategy Nash Equilibrium. The 1–10 game does not have a pure strategy equilibrium, but has a unique mixed strategy equilibrium. In equilibrium, the player selects 10 with probability 0.1, 9 with probability 0.2, 8 with probability 0.3, and 7 with probability 0.4. The beauty contest game has a Nash Equilibrium where every player selects 0.[19] Although the 1–10 game has a mixed strategy equilibrium, the beauty contest is a more complicated game. First, there are several opponents in the beauty contest game, whereas there is only a single opponent in the 1–10 game. Second, the best response in the 1–10 game is obvious: select one fewer than your opponent. This is in contrast to the beauty contest where calculating the best response is less straightforward. Finally, there are different decision rules in the beauty contest: the pure strategy Nash Equilibrium or successive elimination of dominated strategies. By contrast, in the 1–10 game there is only a single decision rule: select one fewer than your opponent. This is because the game neither possesses a pure strategy Nash Equilibrium nor a dominated strategy.

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16 Grade point average ranges from 0.0 to 4.0.

17 We did not ask the subjects about their use of these or other memorization aids.

18 We acknowledge that this design leaves open the possibility that the subject could decide on an action during the instruction stage, thereby reducing the efficacy of the cognitive load.

19 Due to the discrete nature of the action space, there is another equilibrium where every player selects 0.5.

Table 1
Distribution of actions in 1–10 and 11–20 games.

11–20 game, n = 108										
Action	11	12	13	14	15	16	17	18	19	20
	4%	0%	3%	6%	1%	6%	32%	30%	12%	6%
1–10 game, n = 308										
Action	1	2	3	4	5	6	7	8	9	10
	1%	0%	1%	2%	2%	5%	12%	37%	21%	19%

3. Results

3.1. A preliminary look at the cognitive load effects

The subjects reported a significant difference in the difficulty in recalling the large number (*Mean* = 5.93, *SD* = 1.23) and the small number (*Mean* = 6.83, *SD* = 0.52) according to a Wilcoxon signed-rank test, $W = 6798.5$, $p < 0.001$. There are also significant differences between the treatments in the length of time that they spent committing the number to memory. Recall that the subjects were given up to 15 s in order to commit the number to memory.[20] The subjects under a low load had significantly more of the 15 s remaining (*Mean* = 12.80, *SD* = 2.96) than the subjects under a high load (*Mean* = 4.83, *SD* = 4.27), according to a Wilcoxon–Mann–Whitney rank-sum test, $Z = 46.70$, $p < 0.001$. The subjects were each given 12 incentivized memorization tasks, 6 as high load and 6 as low load. Subjects in the low load were correct in 99.03% (1830 of 1848) of the attempts and the subjects in the high load were correct in 96.75% (1788 of 1848) of the attempts.[21] Of the 308 subjects, 249 correctly performed all 12 memorization tasks, 46 correctly performed 11, 8 correctly performed 10, 4 correctly performed 9, and 1 correctly performed 8.

Despite these differences between the treatments, we do not find evidence that the subjects in the high load treatment were unusually impaired. Recall that we posed 2 simple, unincentivized arithmetic questions to each subject, one under a high load and one under a low load. Given 616 arithmetic questions, only 21 incorrect responses were given, 14 under the high load and 7 under the low load. These are not significantly different ($\chi^2(1) = 2.42$, $p = 0.12$). Thus, we do not find evidence that the high load significantly impaired the subjects.

3.2. The 1–10 game

In Table 1, we present the distribution of actions in the 1–10 game and that from the original 11–20 game (Arad and Rubinstein, 2012). In Fig. 2 we characterize the distribution of the choices under high and low load.

It would seem natural that the least sophisticated subject ($L0$) would select 10. The subject who best responds to the $L0$ subjects ($L1$) would select 9. The subject who best responds to $L1$ subjects ($L2$) would select 8, and so on. As such, the response is negatively associated with the strategic sophistication of the subject.

We now analyze actions in the 1–10 game. As the response in the 1–10 game is bounded above at 10 and below at 1, we perform tobit regressions with the action as the dependent variable, subject to these bounds.[22] Throughout the analysis, we include a dummy variable indicating whether the 1–10 game was played under a high load. Additionally, we include a dummy variable indicating whether the subject had taken a game theory course, whether the subject reported being an economics major, and whether the subject is female. We refer to this collection of variables as *Demographics*. We also account for self-reported GPA. Recall that a response to GPA was optional and only 216 of 308 subjects provided a response.

In one condition, which we refer to as the *No information* condition, subjects were not told the load of their opponent. In the other condition, which we refer to as the *Information* condition, subjects were told the load of their opponent. In the first two regressions, we restrict attention to the No information condition. In the second two regressions, we restrict attention to the Information condition. In the Information regressions, we include a dummy variable indicating whether the subject was told that their opponent was under a high load, and the interaction of this dummy with their own load. These variables are, respectively, Opponent HL and Opponent HL * High load. In the last two regressions, we analyze the pooled data. Here we include a variable indicating whether the observation was in the Information condition or not, in addition to the relevant interaction with the load. We summarize this analysis in Table 2.

We find that in the sessions where the subjects were not given information about the load of their opponent, subjects under a high load selected a more sophisticated response. Further, in the pooled data, we find evidence that subjects under a high load were more sophisticated. However, we cannot conclude that there is a relationship between the load and behavior

[20] The z-Tree output specified the time remaining when the Click to Proceed button was pressed. However, there were instances where the output suggested that the decision was made with 99,999 s remaining. This output seems to have occurred if the “Click to Proceed” button was pressed before the clock could begin. In the stage in which the number was given to the subjects, we recoded the 3 instances of the 99,999 output as 16, because 15 s were allotted.

[21] According to a chi-square test, these are significantly different, $\chi^2(1) = 23.10$, $p < 0.001$.

[22] We run tobit regressions since 28 of the 164 subjects in the No information condition selected the upper bound of 10 and 2 selected the lower bound of 1. Additionally, 29 of the 144 subjects in the Information condition selected the upper bound and 1 selected the lower bound.

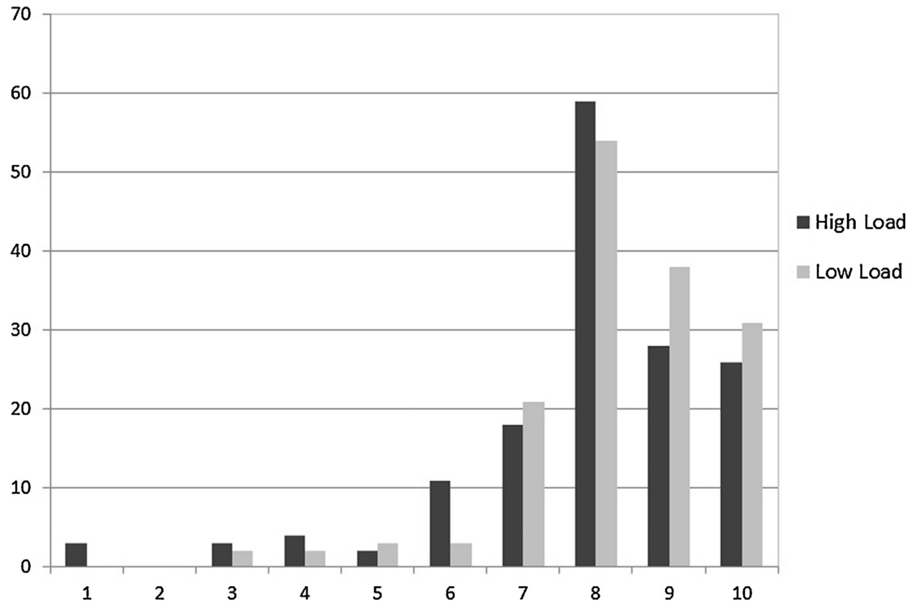

Fig. 2. Number of subjects that selected each of the available actions in the 1–10 game.

Table 2
Tobit regressions: choice in the 1–10 game.

	No information		Information		Pooled	
	(1)	(2)	(3)	(4)	(5)	(6)
High load	−0.631** (0.286)	−0.526* (0.308)	−0.606 (0.493)	−0.767 (0.604)	−0.641** (0.304)	−0.537 (0.363)
Self-reported GPA	–	0.210 (0.391)	–	0.610 (0.561)	–	0.411 (0.336)
Opponent HL	–	–	0.00985 (0.491)	−0.195 (0.611)	–	–
Opponent HL * High load	–	–	0.570 (0.696)	0.872 (0.867)	–	–
Information	–	–	–	–	−0.205 (0.314)	−0.197 (0.362)
Information * High load	–	–	–	–	0.353 (0.445)	0.218 (0.520)
Demographics	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Observations	164	112	144	104	308	216
−2 Log Likelihood	597.84	383.06	546.42	395.19	1148.44	789.02

The tobit regressions are performed with an upper bound of 10 and a lower bound of 1. We do not provide the estimates of the intercepts or the individual demographics variables. Note that * denotes significance at $p < 0.1$, ** at $p < 0.05$, and *** at $p < 0.01$.

in the Information condition. We also note that the GPA variable is not significant in any specification. Additionally, in the Information regressions we do not find evidence that the content of the information of the load of the opponent affected behavior. As we do not find evidence that information about the opponent's load was related to behavior, we do not include it in the analysis of the pooled data. Finally, we note that neither the Information nor the Information*High load variables are significant.[23]

3.3. *The beauty contest game*

Recall that lower responses in the beauty contest are associated with greater strategic sophistication. Also recall that the action space in our beauty contest was the half-integers between 0 and 10. We characterize the distribution of choices by load in Fig. 3.

[23] As stated in the introduction, for every regression that includes the GPA variable, we also ran specifications with the interaction of the high load and GPA variables. The specification associated with regression (6) in Table 2 is the only specification where the interaction is significant ($p = 0.09$).

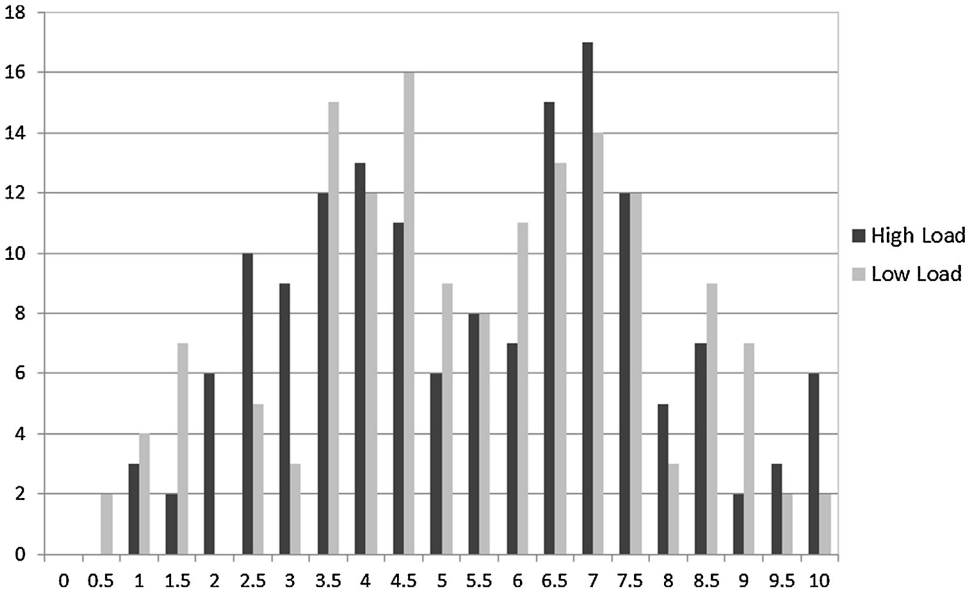

Fig. 3. Number of subjects that selected each of the available actions in the beauty contest game.

Table 3
Tobit regressions: choice in the beauty contest game.

	No information		Information		Pooled	
	(1)	(2)	(3)	(4)	(5)	(6)
High load	0.625	0.933**	−0.716**	−0.762**	0.644*	0.788*
	(0.384)	(0.432)	(0.329)	(0.382)	(0.357)	(0.418)
Self-reported GPA	–	−2.076***	–	−0.0842	–	−1.057***
		(0.547)		(0.507)		(0.387)
Information	–	–	–	–	0.328	0.267
					(0.368)	(0.432)
Information * High load	–	–	–	–	−1.321**	−1.467**
					(0.520)	(0.598)
Demographics	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Observations	164	112	144	104	308	216
−2 Log Likelihood	742.74	490.19	600.92	431.48	1362.66	941.87

The tobit regressions are performed with an upper bound of 10 and a lower bound of 0. We do not provide the estimates of the intercepts or the individual demographics variables. Note that * denotes significance at $p<0.1$, ** at $p<0.05$, and *** at $p<0.01$.

We note that 33% of the subjects (101 of 308) played a dominated strategy of 7 or higher. However, we note that the number of subjects under a high load who selected a dominated strategy (52) is not different than the number of subjects under a low load who selected a dominated strategy (49).[24] This suggests that the results that follow are not driven by dominated actions.

Because of the bounded nature of the action space, we run tobit regressions with choice in the beauty contest as the dependent variable, subject to these bounds.[25] In the Information condition for the beauty contest, the subjects were simply *reminded* of the distribution of the loads within the session. As a result, for the Information condition regressions, we do not include a variable indicating the load of their opponent. The analysis is otherwise equivalent to that summarized in Table 2 and is summarized in Table 3.

In regression (2) of the No Information regressions and in the pooled regressions, we find evidence that subjects under the high load were less strategic than subjects under a low load. However, we find evidence that subjects in the Information condition under high load were more strategic than subjects under a low load. This is consistent with the view that the information about the distribution of the cognitive load was used by the subjects under a high load but not by the subjects under a low load. In other words, here we find evidence that subjects under a high load better used information than the

[24] According to a chi-square test, $\chi^2(1)=0.13$, $p=0.72$.

[25] Despite that in our sample, only 8 subjects selected the upper bound and none selected the lower bound, we run tobit regressions. We do so in order to facilitate the comparison to the analysis of the 1–10 behavior. Further, the tobit results are similar to those with an OLS specification. The OLS analysis is available from the corresponding author upon request.

Table 4
Data for 3 × 3 games.

	Mean
Nash action	0.572
Nash beliefs	0.511

The means are reported for the dummy variables used in our analysis of the 3 × 3 games. Both means are calculated from 3080 observations.

subjects under a low load. We also find that higher GPA subjects selected a more strategic response in the No Information condition and in the pooled data. However, we do not find such a relationship in the Information condition.

We acknowledge that the guesses in our beauty contest game exhibit a puzzlingly large fraction of high guesses.[26] As responses in the 1–10 game are expected to be higher than responses in the beauty contest game, we conjecture that the subjects used their response in the 1–10 game as an anchor for their response in the beauty contest. Unfortunately, the design of this experiment does not permit us to test this conjecture.

3.4. The 3 × 3 games

We introduce the two dependent variables that we will use to characterize strategic sophistication in this setting. The first variable, Nash action, obtains a value of 1 if the subject played the action consistent with the Nash equilibrium, and a 0 otherwise. The second variable, Nash beliefs, obtains a value of 1 if the subject reported the belief that their opponent would play their Nash action, and a 0 otherwise. The means for these variables are reported in Table 4.[27]

We now conduct an analysis with Nash action as the dependent variable. Since the 3 × 3 games are heterogenous, we include two measures to control for the heterogeneity. One independent variable specifies the number of the subject's own dominated strategies. This variable ranges from 0 to 2. Another independent variable specifies the number of the dominated strategies of their opponent. This variable also ranges from 0 to 2. We account for the load by employing a high load dummy variable. We also consider the demographic variables and the self-reported GPA. Additionally, we include controls for the information given to the subject. In particular, we control for the case that the subject was not given any information about the load of their opponent, whether the subject was told that their opponent was under a high load, or whether the subject was told that their opponent was under a low load. From this categorical variable, we are able to determine the behavioral effects of the information about the load of the opponent.

Since we have 10 observations for every subject, we employ a random-effects repeated measures analysis. We estimate an exchangeable covariance matrix, clustered by subject. In other words, we assume a unique correlation between any two observations involving a particular subject. However, we assume that observations involving two different subjects are statistically independent. The regressions are estimated using Generalized Estimating Equations (GEE). Since GEE is not a likelihood-based method, Akaike's Information Criterion is not available. Therefore, we provide the Quasilikelihood information criterion (QIC).[28] We summarize this analysis in Table 5.

We find that the likelihood that subjects played an action consistent with the Nash equilibrium was increasing in the number of their dominated strategies. We also find that subjects under a high load were less sensitive to the changes in the number of their own dominated strategies than subjects under a low load. Also we note the positive relationship between GPA and playing the Nash equilibrium action.[29,30]

While Table 5 suggests a relationship between the load of the subject and the likelihood of playing the Nash equilibrium action, the analysis does not readily lend itself to comparison with the analyses of the 1–10 and beauty contest games. We therefore conduct a similar analysis to that summarized in Table 5, but restrict attention to observations in games that are relatively less complex and observations in games that are relatively more complex. To accomplish this we perform two regressions where we restrict attention to the observations from games where the subject had 1 or 2 dominated strategies. We also perform two regressions where we restrict attention to the observations from games where the subject had 0 dominated strategies. Finally, we perform two regressions on the pooled data and we include a dummy variable that indicates whether the observation was associated with a game where the subject had 1 or 2 dominated strategies, and an interaction with this dummy and the high load dummy. In a sense, one could regard the first two regressions as offering a

[26] We run additional regressions that exclude the subjects that selected a dominated strategy (7 or higher). These results are robust to this specification and are available from the corresponding author upon request.

[27] These values within each game and cognitive load treatment are presented in Table A1 in Appendix A.

[28] For more on QIC, see Pan (2001).

[29] Although not reported in Table 5, we do not find evidence that either the content or the existence of a message about the load of the opponent affected behavior, as measured by the Nash action variable.

[30] We have also analyzed specifications that investigate possible order effects and specifications that account for the round (from 1 to 10) in which the game was played. The qualitative results are not changed under either sets of specifications. Additionally, we do not find order effects, however we find that subjects in higher rounds are significantly more likely to play their Nash action. These regressions are available from the corresponding author upon request.

Table 5
Random-effects logistic regressions: Nash action.

	(1)	(2)	(3)
High load	−0.068	−0.061	−0.234
	(0.209)	(0.211)	(0.238)
Own dominated strategies	0.716***	0.723***	0.786***
	(0.0627)	(0.063)	(0.078)
Other dominated strategies	0.320***	0.323***	0.309***
	(0.060)	(0.060)	(0.075)
High load * Own dominated strategies	−0.162**	−0.163**	−0.213**
	(0.077)	(0.078)	(0.092)
High load * Other dominated strategies	0.147*	0.149*	0.190*
	(0.084)	(0.085)	(0.107)
Self-reported GPA	–	–	0.297**
			(0.136)
Demographics	*No*	*Yes*	*Yes*
Observations	3080	3080	2160
QIC	3842.74	3821.28	2664.19

The random-effects regressions estimate an exchangeable covariance matrix, clustered by subject. We do not provide the estimates of the intercepts, the individual demographics variables, the covariance estimates, or the effects due to the information of the load of the opponent. Regressions (1) and (2) have 3080 observations (308 subjects in 10 periods) and regression (3) has 2160 observations (216 subjects in 10 periods). QIC refers to the Quasi-likelihood information criterion. Finally, * denotes significance at $p<0.1$, ** at $p<0.05$, and *** at $p<0.01$.

Table 6
Random-effects logistic regressions: Nash action.

	Own DS 1 or 2		Own DS 0		Pooled	
	(1)	(2)	(3)	(4)	(5)	(6)
High load	−0.287***	−0.392***	0.0067	−0.039	0.0067	−0.038
	(0.086)	(0.101)	(0.114)	(0.136)	(0.114)	(0.136)
Own DS12	–	–	–	–	1.177***	1.244***
					(0.104)	(0.125)
Own DS12 * High load	–	–	–	–	−0.294**	−0.354**
					(0.124)	(0.144)
Self-reported GPA	–	0.310*	–	0.237	–	0.280**
		(0.173)		(0.180)		(0.1278)
Demographics	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Observations	1848	1296	1232	864	3080	2160
QIC	2332.07	1626.33	1677.03	1175.70	4003.21	2796.27

The random-effects regressions estimate an exchangeable covariance matrix, clustered by subject. We do not provide the estimates of the intercepts, the individual demographics variables, or the covariance estimates. QIC refers to the Quasi-likelihood information criterion. Finally, * denotes significance at $p<0.1$, ** at $p<0.05$, and *** at $p<0.01$.

relatively simple strategic setting, similar to the 1–10 game observations. One could also regard the second two regressions as offering a relatively complex strategic setting, similar to the beauty contest observations. This analysis is summarized in Table 6.

In the relatively simple 3×3 games, subjects under a high load were less likely to play their Nash action. We also find that in these relatively simple games, higher GPA subjects were more likely to play their Nash action. We contrast these results with the analysis of the 1–10 observations, which were summarized in Table 2. There we found evidence that subjects under a high load were more sophisticated than subjects under a low load. Additionally, we did not find evidence of a relationship between GPA and behavior in the 1–10 game.[31]

In relatively complicated 3×3 games, subjects under a high load were no more likely to play their Nash action than were subjects under a low load. Also, we do not find a relationship between GPA and Nash action in the relatively complicated games. We contrast these results with the analysis of the beauty contest observations, which were summarized in Table 3. There we found that subjects under a high load were less sophisticated than subjects under a low load. Additionally, we found evidence that higher GPA subjects were more strategic in the beauty contest game.[32]

Comparing the analyses summarized in Tables 2, 3, and 6, it becomes apparent that the implications of the cognitive load are not persistent across classes of games. In order to better understand this lack of persistence, we perform the analysis identical to that summarized in Table 6 but we employ Nash beliefs, rather than Nash action, as the dependent variable. This analysis is summarized in Table 7.

[31] We also note that Table A2 conducts the analysis of the first two regressions in Table 6 but restricted to the Information and No information treatments. Unlike the analysis from the 1–10 game in Table 2, we do not find evidence that these treatments affected behavior according to the Nash action measure.

[32] We also note that Table A3 conducts the analysis summarized in Table 6 but restricts attention to the Information and No information treatments. Unlike the analysis from the beauty contest game, these treatments do not affect behavior according to the Nash action measure.

Table 7
Random-effects logistic regressions: Nash beliefs.

	Own DS 1 or 2		Own DS 0		Pooled	
	(1)	(2)	(3)	(4)	(5)	(6)
High load	−0.098	−0.148*	0.325**	0.328*	0.325**	0.330*
	(0.073)	(0.088)	(0.146)	(0.173)	(0.147)	(0.174)
Own DS12	–	–	–	–	0.926***	0.936***
					(0.105)	(0.120)
Own DS12 * High load	–	–	–	–	−0.424***	−0.477***
					(0.158)	(0.181)
Self-reported GPA	–	0.490***	–	0.123	–	0.344***
		(0.159)		(0.144)		(0.125)
Demographics	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Observations	1848	1296	1232	864	3080	2160
QIC	2513.57	1758.07	1661.72	1168.93	4171.46	2924.91

The random-effects regressions estimate an exchangeable covariance matrix, clustered by subject. We do not provide the estimates of the intercepts, the individual demographics variables, or the covariance estimates. QIC refers to the Quasi-likelihood information criterion. Finally, * denotes significance at $p < 0.1$, ** at $p < 0.05$, and *** at $p < 0.01$.

We find that in the relatively simple games there is only weak evidence that the subjects under a high load exhibited different beliefs than the subjects under low load. However, in the relatively complex games, we find that the subjects under a high load believed that their opponents were more sophisticated than did the subjects under a low load. Further, we note that the relationship between cognitive load and strategic sophistication, as measured by Nash action, is different from the relationship between cognitive load and strategic sophistication, as measured by Nash beliefs. This suggests that beliefs and actions might not be as closely related as standard game theory would predict.

4. Conclusion

We have described an experiment where subjects played different games while under a cognitive load. These games included ten 3×3 games, the 1–10 game, and the beauty contest game. Through our single cognitive load manipulation we observed that the relationship between cognitive load and strategic sophistication was not persistent across different classes of games.

In the relatively complicated beauty contest game, we observe that subjects under a high load played less strategically. We also find that in relatively simple 3×3 games, subjects under a high load were less likely to play their Nash equilibrium action than were subjects under a low load. These are settings in which subjects under a high load were less strategic than subjects under a low load.

On the other hand, in the relatively uncomplicated 1–10 game we observe that subjects under a high load selected a more strategic response than subjects under a low load. Additionally in the beauty contest game, subjects under a high load who were reminded of the distribution of the load of their opponents selected a more strategic action than the subjects under a high load who were not reminded of the distribution. However, this relationship does not exist among subjects under a low load. These are settings in which subjects under a high load were more strategic than subjects under a low load.

In order to better understand this lack of persistence across games, we also analyze beliefs in the 3×3 games. We find that the relationship between cognitive load and actions is different than the relationship between cognitive load and beliefs. This suggests that actions and beliefs are not as closely related as predicted by standard game theory. These results are consistent with the view that the allocation of cognitive effort to the deliberation of actions and beliefs is performed in a parallel fashion.

Our evidence suggests that constraints on cognitive resources can affect both the computations involving optimal behavior and the perception of the subjects' relative standing in the distribution of available cognitive resources. To the extent that subjects under a high cognitive load are similar to the condition of having a diminished cognitive ability, our results suggest that a lower measure of cognitive ability will not necessarily produce less sophisticated behavior, particularly when the ability to make the necessary computations is not a binding constraint.[33]

We hope that our findings are helpful in the efforts to improve models of strategic sophistication. One promising proposal is that subjects, given a cognitive cost of computing higher levels of strategic reasoning, select an *optimal* level of strategic reasoning (Alaoui and Penta, 2015). Consistent with this model, there is evidence that subjects respond to an increase in incentives and an increase in the perceived sophistication of their opponent by selecting a more sophisticated action.[34] Our results suggest that an increase in the cost of reasoning could actually increase the observed sophistication in some settings but it is not obvious when this will be the case.

[33] See Gigerenzer and Brighton (2009) for more on the non-monotonic relationship between computational capacity and rational behavior.
[34] Cubel and Sanchez-Pages (2014) study the gender differences in the response to incentives in the beauty contest.

Additionally, we hope that this research will encourage the use of the cognitive load manipulation in any setting in which cognition plays a crucial role in behavior. Perhaps the most obvious application of cognitive load is in the rational inattention literature.[35] Rational inattention models assume that decision makers are unable to process all available information, however they optimally allocate their limited attention. It would seem profitable to investigate these models in the laboratory by manipulating the limits of attention via cognitive load.

We acknowledge that there is much work to be done on this topic. For instance, we were not able to observe the order in which the subjects provided their actions and their beliefs. In the future, it would be interesting to observe if there is a relationship between the cognitive load manipulation and the order of the selection of actions and beliefs. We also hope to learn whether there is a differential effect of not eliciting beliefs. Perhaps the elicitation of beliefs reminds the subjects under a high load to devote cognitive effort, where that effort would possibly not occur if beliefs were not elicited. We also do not know if a different means of controlling for beliefs would lead to qualitatively similar behavior. Further, as we controlled for beliefs, we also affected higher order beliefs. A careful experimental setup could help distinguish between the effects of first order and higher order beliefs. Additionally, although we did not observe order effects within the 3 × 3 games, our design does not allow us to test for order effects related to the 1–10 and beauty contest games. We are interested to learn if such order effects can be observed. Finally, we are interested to learn the implications of a more difficult high load (more than 9 binary digits) and a less difficult low load (less than 3 binary digits) because it is not obvious to us that a monotonic relationship would emerge.

Appendix A.

Fig. A1. The screen during 3 × 3 games without information of the load of the opponent.

[35] See Sims (2003), Reis (2006), Maćkowiak and Wiederholt (2009), Wiederholt (2010), Bordalo et al. (2014), Dahremöller and Fels (2015), and Persson (2012). See Cheremukhin et al. (2015) for an experiment involving rational inattention.

Fig. A2. The screen during 3 × 3 games with information of the load of the opponent.

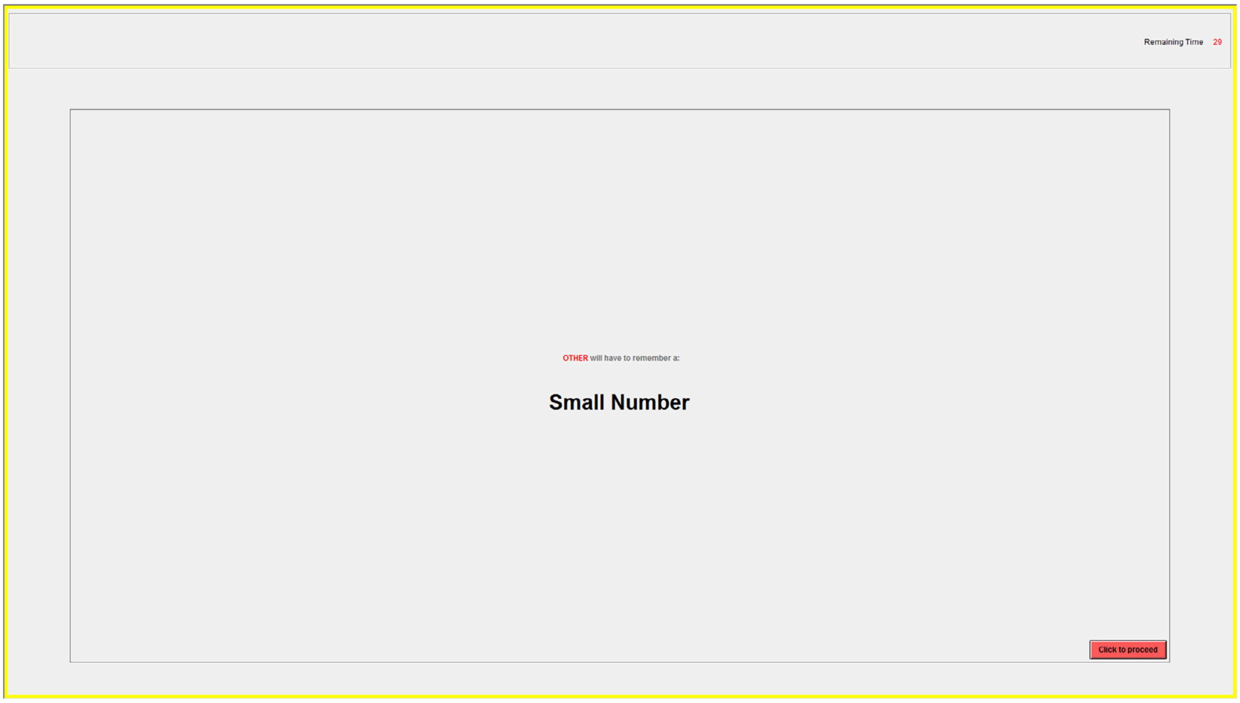

Fig. A3. Screen indicating the load of the opponent.

Table A1
Summary statistics for 3 × 3 games.

Game/role	Nash action		Nash beliefs	
	High	Low	High	Low
1A Row	0.78	0.73	0.81	0.75
1A Column	0.77	0.85	0.76	0.71
1B Row	0.83	0.88	0.73	0.75
1B Column	0.68	0.68	0.79	0.78
2A Row	0.69	0.73	0.64	0.67
2A Column	0.55	0.71	0.57	0.67
2B Row	0.64	0.70	0.60	0.67
2B Column	0.70	0.63	0.73	0.68
3A Row	0.85	0.83	0.34	0.27
3A Column	0.59	0.47	0.93	0.89
3B Row	0.42	0.55	0.88	0.82
3B Column	0.81	0.89	0.23	0.29
4A Row	0.58	0.49	0.10	0.14
4A Column	0.23	0.29	0.25	0.34
4B Row	0.27	0.48	0.40	0.57
4B Column	0.67	0.68	0.38	0.21
5A Row	0.37	0.42	0.12	0.12
5A Column	0.20	0.15	0.41	0.45
5B Row	0.28	0.24	0.37	0.39
5B Column	0.33	0.34	0.18	0.09
Average	0.55	0.59	0.52	0.50
Pooled	0.572		0.511	

The fraction of observations within both load treatments in every 3 × 3 game that satisfy the condition of the Nash action, and Nash beliefs. The game/role designations are stated from the perspective of Fig. 1. For instance, 1A Column represents the column player in Game 1A. Recall that the strategic setting for the row (column) player in the A version is similar to that for the column (row) player in the B version.

Table A2
Random-effects logistic regressions: Nash action in DS 1 or 2 games.

	No information		Information		Pooled	
	(1)	(2)	(3)	(4)	(5)	(6)
High load	−0.341***	−0.402***	−0.225*	−0.388***	−0.340***	−0.400***
	(0.117)	(0.140)	(0.128)	(0.147)	(0.117)	(0.140)
Self-reported GPA	–	0.546**	–	0.0400	–	0.299*
		(0.242)		(0.2679)		(0.173)
Information	–	–	–	–	0.234	0.173
					(0.161)	(0.188)
Information * High load	–	–	–	–	0.116	0.0156
					(0.173)	(0.202)
Demographics	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Observations	984	672	864	624	1848	1296
QIC	1279.88	868.07	1047.14	761.49	2327.66	1628.31

The random-effects regressions estimate an exchangeable covariance matrix, clustered by subject. We do not provide the estimates of the intercepts, the individual demographics variables, or the covariance estimates. QIC refers to the Quasi-likelihood information criterion. Finally, * denotes significance at $p<0.1$, ** at $p<0.05$, and *** at $p<0.01$.

Table A3
Random-effects logistic regressions: Nash action in 0 games.

	No information		Information		Pooled	
	(1)	(2)	(3)	(4)	(5)	(6)
High load	0.128	0.074	−0.130	−0.164	0.127	0.0743
	(0.154)	(0.183)	(0.171)	(0.207)	(0.153)	(0.184)
Self-reported GPA	–	0.012	–	0.629**	–	0.238
		(0.214)		(0.276)		(0.180)
Information	–	–	–	–	0.221	0.107
					(0.165)	(0.192)
Information * High load	–	–	–	–	−0.256	−0.234
					(0.228)	(0.273)
Demographics	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Observations	656	448	576	416	1232	864
QIC	888.24	615.90	787.92	562.32	1679.31	1179.03

The random-effects regressions estimate an exchangeable covariance matrix, clustered by subject. We do not provide the estimates of the intercepts, the individual demographics variables, or the covariance estimates. QIC refers to the Quasi-likelihood information criterion. Finally, * denotes significance at $p<0.1$, ** at $p<0.05$, and *** at $p<0.01$.

Appendix B. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.jebo.2016.02.006.

References

Agranov, M., Caplin, A., Tergiman, C., 2015. Naive play and the process of choice in guessing games. J. Econ. Sci. Assoc. 1 (2), 146–157.
Agranov, M., Potamites, E., Schotter, A., Tergiman, C., 2012. Beliefs and endogenous cognitive levels: an experimental study. Game. Econ. Behav. 75 (2), 449–463.
Alaoui, L., Penta, A., 2015. Endogenous depth of reasoning. Rev. Econ. Stud. (forthcoming).
Allen, R.J., Baddeley, A.D., Hitch, G.J., 2006. Is the binding of visual features in working memory resource-demanding? J. Exp. Psychol. Gen. 135 (2), 298–313.
Alloway, R.G., Alloway, T.P., 2013. Working memory: an introduction. In: Alloway, T.P., Alloway, R.G. (Eds.), Working Memory: The Connected Intelligence. Psychology Press, New York, pp. 3–12.
Allred, S., Crawford, L.E., Duffy, S., Smith, J., 2015. Working Memory and Spatial Judgments: Cognitive Load Increases the Central Tendency Bias. Working Paper. Rutgers University, Camden.
Andersson, O., Holm, H., Tyran, J.R., Wengström, E., 2015. Risk aversion relates to cognitive ability: preferences or noise? J. Eur. Econ. Assoc. (forthcoming).
Arad, A., Rubinstein, A., 2012. The 11–20 money request game: a level-k reasoning study. Am. Econ. Rev. 112 (7), 3561–3573.
Arruñada, B., Casari, M., Pancotto, F., 2015. Pro-sociality and strategic reasoning in economic decisions. Front. Behav. Neurosci. 9, Article 140.
Baghestanian, S., Frey, S., 2015. GO figure: analytic and strategic skills are separable. J. Behav. Exp. Econ. (forthcoming).
Ballinger, T.P., Hudson, E., Karkoviata, L., Wilcox, N.T., 2011. Saving behavior and cognitive abilities. Exp. Econ. 14, 349–374.
Bayer, R., Renou, L., 2012. Logical Abilities and Behavior In Strategic-Form Games. Working Paper. University of Leicester.
Beauchamp, J., Cesarini, D., Johannesson, M., 2011. The Psychometric Properties of Measures of Economic Risk Preferences. Working Paper. New York University.
Benjamin, D., Brown, S., Shapiro, J., 2013. 'Who is Behavioral?' Cognitive ability and anomalous preferences. J. Eur. Econ. Assoc. 11 (6), 1231–1255.
Ben-Ner, A., Kong, F., Putterman, L., 2004. Share and share alike? Gender-pairing, personality, and cognitive ability as determinants of giving. J. Econ. Psychol. 25, 581–589.
Bordalo, P., Gennaioli, N., Shleifer, A., 2014. Competition for attention. Rev. Econ. Stud. (forthcoming).
Brañas-Garza, P., Garcia-Muñoz, T., Hernan Gonzalez, R., 2012. Cognitive effort in the beauty contest game. J. Econ. Behav. Organ. 83 (2), 254–260.
Brañas-Garza, P., Guillen, P., Lopez del Paso, R., 2008. Math skills and risk attitudes. Econ. Lett. 99, 332–336.
Brañas-Garza, P., Espinosa, M.P., Rey-Biel, P., 2011. Travelers' types. J. Econ. Behav. Organ. 78, 25–36.
Brandstätter, H., Güth, W., 2002. Personality in dictator and ultimatum games. Cen. Eur. J. Oper. Res. 10 (3), 191–215.
Buckert, M., Oechssler, J., Schwieren, C., 2013. Imitation Under Stress. Working Paper. University of Heidelberg.
Burgess, G.C., Gray, J.R., Conway, A., Braver, T.S., 2011. Neural mechanisms of interference control underlie the relationship between fluid intelligence and working memory span. J. Exp. Psychol. Gen. 140 (4), 674–692.
Burchardi, K.B., Penczynski, S.P., 2014. Out of your mind: eliciting individual reasoning in one shot games. Game. Econ. Behav. 84, 39–57.
Burks, S.V., Carpenter, J.P., Götte, L., Rustichini, A., 2009. Cognitive skills explain economic preferences, strategic behavior, and job attachment. Proc. Natl. Acad. Sci. U.S.A. 106 (19), 7745–7750.
Burnham, T.C., Cesarini, D., Johannesson, M., Lichtenstein, P., Wallace, B., 2009. Higher cognitive ability is associated with lower entries in a p-beauty contest. J. Econ. Behav. Organ. 72, 171–175.
Camerer, C.F., Ho, T.H., Chong, J.K., 2004. A cognitive hierarchy model of games. Q. J. Econ. 119 (3), 861–898.
Cappelletti, D., Güth, W., Ploner, M., 2011. Being of two minds: ultimatum offers under cognitive constraints. J. Econ. Psychol. 32 (6), 940–950.
Carpenter, J., Graham, M., Wolf, J., 2013. Cognitive ability and strategic sophistication. Game. Econ. Behav. 80 (1), 115–130.
Chen, C.C., Chiu, I., Smith, J., Yamada, T., 2013a. Too smart to be selfish? Measures of cognitive ability, social preferences, and consistency. J. Econ. Behav. Organ. 90, 112–122.
Chen, C.T., Huang, C.Y., Wang, J.T., 2013b. A Window of Cognition: Eyetracking the Reasoning Process in Spatial Beauty Contest Games. Working Paper. National Taiwan University.
Chen, S.H., Du, Y.R., Yang, L.X., 2014. Cognitive capacity and cognitive hierarchy: a study based on beauty contest experiments. J. Econ. Interact. Coord. 9 (1), 69–105.
Cheremukhin, A., Popova, A., Tutino, A., 2015. A theory of discrete choice with information costs. J. Econ. Behav. Organ. 113, 34–50.
Cokely, E.T., Kelley, C.M., 2009. Cognitive abilities and superior decision making under risk: a protocol analysis and process model evaluation. Judgm. Decis. Mak. 4 (1), 20–33.
Cole, M.W., Yarkoni, T., Repovš, G., Anticevic, A., Braver, T.S., 2012. Global connectivity of prefrontal cortex predicts cognitive control and intelligence. J. Neurosci. 32 (26), 8988–8999.
Conway, A., Kane, M.J., Engle, R.W., 2003. Working memory capacity and its relation to general intelligence. Trends Cogn. Sci. 7 (12), 547–552.
Coricelli, G., Nagel, R., 2009. Neural correlates of depth of strategic reasoning in medial prefrontal cortex. Proc. Natl. Acad. Sci. U.S.A. 106 (23), 9163–9168.
Coricelli, G., Nagel, R., 2012. The neural basis of bounded rational behavior. Rev. Intern. Sociol. 70, 39–52.
Cornelissen, G., Dewitte, S., Warlop, L., 2011. Are social value orientations expressed automatically? Decision making in the dictator game. Pers. Soc. Psychol. B 37 (8), 1080–1090.
Costa-Gomes, M.A., Crawford, V.P., Broseta, B., 2001. Cognition and behavior in normal-form games: an experimental study. Econometrica 69 (5), 1193–1235.
Costa-Gomes, M.A., Crawford, V.P., 2006. Cognition and behavior in two-person guessing games: an experimental study. Am. Econ. Rev. 96 (5), 1737–1768.
Costa-Gomes, M., Weizsacker, G., 2008. Stated beliefs and play in normal-form games. Rev. Econ. Stud. 75, 729–762.
Crawford, V.P., 2008. Look-ups as the windows of the strategic soul. In: Caplin, A., Schotter, A. (Eds.), The Foundations of Positive and Normative Economics: A Handbook. Oxford University Press, Oxford, pp. 249–280.
Crawford, V.P., Costa-Gomes, M.A., Iriberri, N., 2013. Structural models of nonequilibrium strategic thinking: theory, evidence, and applications. J. Econ. Lit. 51 (1), 5–62.
Cubel, M., Sanchez-Pages, S., 2014. Gender Differences and Stereotypes in the Beauty Contest. Working Paper. Universitat de Barcelona.
Dahremöller, C., Fels, M., 2015. Product lines, product design and limited attention. J. Econ. Behav. Organ. 119, 437–456.
de Sousa, J., Hollard, G., Terracol, A., 2013. Non-Strategic Players Are the Rule Rather Than the Exception. Working Paper. Université Paris 1.
Deck, C., Jahedi, S., 2015. The effect of cognitive load on economic decision making: a survey and new experiments. Eur. Econ. Rev. 78, 97–119.
Devetag, G., Warglien, M., 2003. Games and phone numbers: do short-term memory bounds affect strategic behavior? J. Econ. Psychol. 24, 189–202.
Dewitte, S., Pandelaere, M., Briers, B., Warlop, L., 2005. Cognitive Load Has Negative After Effects on Consumer Decision Making. Working Paper. Katholieke Universiteit Leuven, Belgium.
Dickinson, D.L., McElroy, T., 2010. Rationality around the clock: sleep and time-of-day effects on guessing game responses. Econ. Lett. 108 (2), 245–248.
Dickinson, D.L., McElroy, T., 2012. Circadian effects on strategic reasoning. Exp. Econ. 15 (3), 444–459.
Dittrich, M., Leipold, K., 2014. Clever and Selfish? On the Relationship Between Strategic Reasoning and Social Preferences. Working Paper. Chemnitz University of Technology.

Dohmen, T., Falk, A., Huffman, D., Sunde, U., 2010. Are risk aversion and impatience related to cognitive ability? Am. Econ. Rev. 100 (3), 1238–1260.
Duffy, S., Naddeo, J., Owens, D., Smith, J., 2016. Cognitive Load and Mixed Strategies: On Brains and Minimax. Working Paper. Rutgers University, Camden.
Duffy, S., Smith, J., 2014. Cognitive load in the multi-player prisoner's dilemma game: are there brains in games? J. Behav. Exp. Econ. 51, 47–56.
Epley, N., Gilovich, T., 2006. The anchoring-and-adjustment heuristic: why the adjustments are insufficient. Psychol. Sci. 17 (4), 311–318.
Fehr, D., Huck, S., 2015. Who knows it is a game? On strategic awareness and cognitive ability. Exp. Econ. (forthcoming).
Fischbacher, U., 2007. z-Tree: Zurich toolbox for ready-made economic experiments. Exp. Econ. 10 (2), 171–178.
Frederick, S., 2005. Cognitive reflection and decision making. J. Econ. Perspect. 19 (4), 25–42.
Georganas, S., Healy, P.J., Weber, R., 2015. On the persistence of strategic sophistication. J. Econ. Theory 159, 369–400.
Gilbert, D.T., Pelham, B.W., Krull, D.S., 1988. On cognitive busyness: when person perceivers meet persons perceived. J. Pers. Soc. Psychol. 54 (5), 733–740.
Gill, D., Prowse, V., 2015. Cognitive ability, character skills, and learning to play equilibrium: a level-k analysis. J. Pol. Econ. (forthcoming).
Gigerenzer, G., Brighton, H., 2009. Homo heuristicus: why biased minds make better inferences. Topics Cogn. Sci. 1 (1), 107–143.
Grimm, V., Mengel, F., 2012. An experiment on learning in a multiple games environment. J. Econ. Theory 147 (6), 2220–2259.
Hanaki, N., Jacquemet, N., Luchini, S., Zylbersztejn, A., 2015. Cognitive ability and the effect of strategic uncertainty. Theor. Decis., 1–21.
Hauge, K.E., Brekke, K.A., Johansson, L.O., Johansson-Stenman, O., Svedsäter, H., 2015. Keeping others in our mind or in our heart? Distribution games under cognitive load. Exp. Econ. (forthcoming).
Hinson, J.M., Jameson, T.L., Whitney, P., 2002. Somatic markers, working memory, and decision making. Cogn. Affect. Behav. Neurosci. 2 (4), 341–353.
Hinson, J.M., Jameson, T.L., Whitney, P., 2003. Impulsive decision making and working memory. J. Exp. Psychol. Learn. 29 (2), 298–306.
Jones, G., 2008. Are smarter groups more cooperative? Evidence from prisoner's dilemma experiments, 1959–2003. J. Econ. Behav. Organ. 68, 489–497.
Jones, M.T., 2014. Strategic complexity and cooperation: an experimental study. J. Econ. Behav. Organ. 106, 352–366.
Kane, M.J., Hambrick, D.Z., Conway, A., 2005. Working memory capacity and fluid intelligence are strongly related constructs: comment on Ackerman, Beier, and Boyle (2005). Psychol. B 131 (1), 66–71.
Kiss, H.J., Rodriguez-Lara, I., Rosa-García, A., 2015. Think twice before running! Bank runs and cognitive abilities. J. Behav. Exp. Econ. (forthcoming).
Maćkowiak, B., Wiederholt, M., 2009. Optimal sticky prices under rational inattention. Am. Econ. Rev. 99 (3), 769–803.
Mann, T., Ward, A., 2007. Attention, self-control, and health behaviors. Curr. Dir. Psychol. Sci. 16 (5), 280–283.
Milinski, M., Wedekind, C., 1998. Working memory constrains human cooperation in the Prisoner's Dilemma. Proc. Natl. Acad. Sci. U.S.A. 95 (23), 13755–13758.
Millet, K., Dewitte, S., 2007. Altruistic behavior as a costly signal of general intelligence. J. Res. Pers. 41, 316–326.
Milosavljevic, M., Navalpakkam, V., Koch, C., Rangel, A., 2012. Relative visual saliency differences induce sizable bias in consumer choice. J. Con. Psychol. 22 (1), 67–74.
Morey, C.C., Bieler, M., 2013. Visual short-term memory always requires general attention. Psycho. B Rev. 20 (1), 163–170.
Morey, C.C., Cowan, N., 2004. When visual and verbal memories compete: evidence of cross-domain limits in working memory. Psychon. B Rev. 11 (2), 296–301.
Nagel, R., 1995. Unraveling in guessing games: an experimental study. Am. Econ. Rev. 85 (5), 1313–1326.
Oberauer, K., Schulze, R., Wilhelm, O., Süß, H.M., 2005. Working memory and intelligence – their correlation and their relation: comment on Ackerman, Beier, and Boyle (2005). Psychol. B 131 (1), 61–65.
Oechssler, J., Roider, A., Schmitz, P.W., 2009. Cognitive abilities and behavioral biases. J. Econ. Behav. Organ. 72, 147–152.
Palacios-Huerta, I., 2003. Learning to open Monty Hall's doors. Exp. Econ. 6 (3), 235–251.
Palacios-Huerta, I., Volij, O., 2009. Field centipedes. Am. Econ. Rev. 99 (4), 1619–1635.
Pan, W., 2001. Akaike's information criterion in generalized estimating equations. Biometrics 57, 120–125.
Persson, P., 2012. Attention Manipulation and Information Overload. Working Paper. Columbia University.
Ponti, G.B., Rodriguez-Lara, I., 2015. Social preferences and cognitive reflection: evidence from dictator game experiment. Front. Behav. Neurosci. 9, Article 146.
Proto, E., Rustichini, A., Sofianos, A., 2014. Higher Intelligence Groups Have Higher Cooperation Rates in the Repeated Prisoner's Dilemma. Working Paper. University of Warwick.
Putterman, L., Tyran, J.R., Kamei, K., 2011. Public goods and voting on formal sanction schemes. J. Pub. Econ. 95, 1213–1222.
Reis, R., 2006. Inattentive consumers. J. Monetary Econ. 53, 1761–1800.
Rey-Biel, P., 2009. Equilibrium play and best response to (stated) beliefs in normal form games. Game. Econ. Behav. 65 (2), 572–585.
Roch, S.G., Lane, J., Samuelson, C.D., Allison, S.T., Dent, J., 2000. Cognitive load and the equality heuristic: a two-stage model of resource overconsumption in small groups. Organ. Behav. Human Decis. Proc. 83 (2), 185–212.
Rydval, O., 2011. The Causal Effect of Cognitive Abilities on Economic Behavior: Evidence from a Forecasting Task with Varying Cognitive Load. Working Paper. CERGE-EI.
Rydval, O., Ortmann, A., 2004. How financial incentives and cognitive abilities affect task performance in laboratory settings: an illustration. Econ. Letl. 85, 315–320.
Samson, K., Kostyszyn, P., 2015. Effects of cognitive load on trusting behavior – an experiment using the trust game. PLOS ONE 10 (5), e0127680.
Sanjurjo, A., 2015. Search, memory, and choice error: an experiment. PLOS ONE 10 (6), e0126508.
Sanjurjo, A., 2014. Search with Multiple Attributes: Theory and Empirics. Working Paper. University of Alacant.
Schulz, J.F., Fischbacher, U., Thöni, C., Utikal, V., 2014. Affect and fairness: dictator games under cognitive load. J. Econ. Psychol. 41, 77–87.
Schnusenberg, O., Gallo, A., 2011. On cognitive ability and learning in a beauty contest. J. Econ. Educ. 11 (1), 13–24.
Shiv, B., Fedorikhin, A., 1999. Heart and mind in conflict: the interplay of affect and cognition in consumer decision making. J. Cons. Res. 26 (3), 278–292.
Sims, C., 2003. Implications of rational inattention. J. Monetary Econ. 50 (3), 665–690.
Slonim, R.L., 2005. Competing against experienced and inexperienced players. Exp. Econ. 8, 55–75.
Stahl, D., Wilson, P., 1994. Experimental evidence on players' models of other players. J. Econ. Behav. Organ. 25, 309–327.
Stahl, D., Wilson, P., 1995. On players' models of other players: theory and experimental evidence. Game. Econ. Behav. 10, 218–254.
Süß, H.M., Oberauer, K., Wittmann, W.W., Wilhelm, O., Schulze, R., 2002. Working-memory capacity explains reasoning ability – and a little bit more. Intelligence 30 (3), 261–288.
Swann, W.B., Hixon, G., Stein-Seroussi, A., Gilbert, D.T., 1990. The fleeting gleam of praise: cognitive processes underlying behavioral reactions to self-relevant feedback. J. Pers. Soc. Psychol. 59 (1), 17–26.
Van den Bos, K., Peters, S.L., Bobocel, D.R., Ybema, J.F., 2006. On preferences and doing the right thing: satisfaction with advantageous inequity when cognitive processing is limited. J. Exp. Soc. Psychol. 42, 273–289.
van't Veer, A.E., Stel, M., van Beest, I., 2014. Limited capacity to lie: cognitive load interferes with being dishonest. Judgm. Dec. Mak. 9 (3), 199–206.
Ward, A., Mann, T., 2000. Don't mind if i do: disinhibited eating under cognitive load. J. Pers. Soc. Psychol. 78 (4), 753–763.
Whitney, P., Rinehart, C.A., Hinson, J.M., 2008. Framing effects under cognitive load: the role of working memory in risky decisions. Psychon. B Rev. 15 (6), 1179–1184.
Wiederholt, M., 2010. Rational inattention. In: Durlauf, S., Blume, L. (Eds.), The New Palgrave Dictionary of Economics, Online Edition. Palgrave Macmillan.
Zokaei, N., Heider, M., Husain, M., 2014. Attention is required for maintenance of feature binding in visual working memory. Q. J. Exp. Psychol. 67 (6), 1191–1213.