Effects of Competition on Human Cognitive Effort

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Abstract

Effects of competition on human mental effort is an interesting phenomenon and understanding its underlying cognitive mechanisms can enable a range of practical applications. In this paper, we examined how competition factors into human cognitive effort by empirically determining if and how it can boost performance in simple mental tasks under different degrees of competition. We conducted a web-based experiment involving a simple number memorization task on 38 healthy participants. Participants were asked to memorize 7-digit numbers, and their goal was to defeat opponents at different difficulty levels by achieving higher overall scores at the end of 1 minute rounds.Statistical analyses were performed on the gathered empirical data from this experiment to gain valuable insights regarding the effects of competition on human cognitive effort. We observed that addition of a head-to-head competing agent caused a significant increase in participant performance. Furthermore, we speculate that the extra cognitive effort in presence of competition depends on the participant's anticipated effort for defeating the opponent with some certainty.

Keywords: Cognition, competition, resource rationality, memorization, number game, time-accuracy trade off

Introduction

To understand human intelligence, one needs to consider the fundamental limitations that apply to human beings such as limited time, limited computation, and limited communication. Given these limitations, humans usually take a resource-rational approach in their actions and demonstrate interesting behaviors in cognitive tasks. One of such interesting phenomena can be seen in the relationship between mental effort and competition. Understanding the mechanisms of human cognitive effort and its relationship with competition is a challenging task. We address this challenge by empirically analyzing the effects of adding a head-to-head rival to a simple number memorization game. We expect to see that adding an opponent to such a winner-takes-all game will significantly boost participant performance. Upon a closer examination of the participant's performance, we hypothesize that participants will go through a time-accuracy trade-off that is proportional to the difficulty of the competing agent.

Previous Work

One of the earlier sources of motivation of this research was the paradoxical game called *the dollar auction game* which demonstrates how people can be compelled to make irrational decisions in the presence of competition (Shubik,). The game involves two participants bidding on a dollar bill. Although the highest bidder receives the bill, both participants must pay the the amount that they offered at the end. The dollar auction game illustrates how people can spend a great amount of their resources (even to the point of making irrational decisions) in order to outbid their competition. Shubik explains this phenomenon by the ”escalation of commitment” (Shubik,). Our problem of cognitive effort in a winner-takes-all memorization game demonstrates a similar setup in the sense that both participants *spend* their limited cognitive resources in pursuit of defeating each other but there can only be one winner at the end. We aim to empirically determine how much people can push their boundaries in such a time-constraint memorization game and whether we can observe a similar irrational behavior against extremely difficult opponent levels.

Previous research on the effect of competition on mental effort has empirically shown that elements of competition, such as a head-to-head rivalry or time pressure, can fuel competitive motivation and introduce a “desire to win” (Malhotra,). Similarly, early work on task motivation has shown that “hard goals produce a higher level of performance (output) than easy goals” (Locke,). However, having bounded computational resources, humans face a trade-off between accuracy and speed (Lieder, Griffiths, & Goodman,) in the pursuit of maximizing their chances of winning against a competitive agent. Our work also attempts to empirically determine the degree of such a trade-off by performing statistical analyses of the experiment data.

Experiment Design and Implementation

The experiment constitutes of ten one-minute rounds of a number memorization game. In each round the participant is repeatedly given 7-digit numbers to memorize and is awarded points depending on if they can enter the number into the game correctly. On rounds without an opponent, the goal is to win as many points as they can, and when the opponent is introduced the goal is to get more points than the opponent. The experiment is available at: https://psy454-number-game.herokuapp.com/.

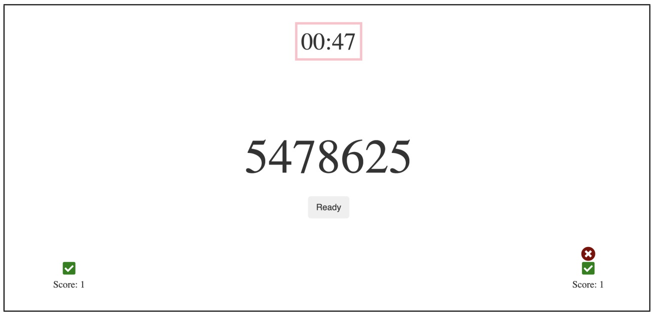

Figure 1: A sample screenshot from a round with opponent

Web Application Design

When a participant navigates to the web application they are first presented with instructions. After reading the instructions the first round of the game starts.

Each round of the game lasts for a minute. There is a visible timer at the top of the page. In the middle of the page, a 7 digit number appears and right below the number there is a **Ready** button. The participant can take as long as they need during the round to memorize the 7 digit number, once they think they memorized the number they are expected to click ready. Afterwards, a text input area appears. Here they are expected to enter the 7 digit number they just memorized. Once they enter some input they are expected to click the **Confirm** button to indicate that they have entered the memorized number. On the left side of the page there is a column reserved for the user's score history.Once they click confirm if the answer was correct a green tick will be added to this column and if their answer was incorrect a red cross will be added to this column. They can see a history of all their answers in this column as well as their overall score at bottom left. Once the timer exhausts 60 seconds the user is provided their results and a next game button.

The first three rounds of the game is without an opponent. Here we aim to gather benchmark data on a user's behavior without an opponent while also giving them a chance to get used to the game. After the first three rounds they are given another set of instructions introducing the opponent. No information on the opponent is provided except that they see the same numbers as the participant. Even though the opponents are simple algorithms with predetermined parameters, we wanted participants to believe that their opponent was another human. They are told that their goal is to beat the opponent, which emphasizes to the user that they should notice the opponent's behavior.

The participant plays 7 rounds of the game with opponents of various difficulties. The structure of the game stays the same as the game without opponent. The difference in the website is the opponent score column. Similar to the participant score column, opponent's column is populated with ticks and crosses over the 60 seconds. The participant can see the opponent's score at the bottom of the right side of the web page as well as the opponent's score history. Once the round is over, the opponent is provided with a statement indicating if they won, lost or tied against the opponent before they are expected to move onto the next round.

Opponent Design

The opponent presented to the participants is artificial. There are five levels of opponents. The opponent is simulated using randomizers to give a less artificial feel. Each participants plays against each level of opponent at least once, and each participant is assigned two other levels randomly. The order of the difficulties are also shuffled. The level between 1 and 5 is subtracted from 9 to give a frequency f. Each f seconds the opponent guesses a number. The accuracy of the opponent guesses is also determined using a randomizer. The opponent's accuracy starts from 0.5 at level 1 and increases by 7.5% at each difficulty level. Table 1 shows the average score each level of opponent is expected to get.

Table 1: Opponent Average Performance

Opponent Difficulty	Expected Score
Level 1	4
Level 2	5
Level 3	7
Level 4	9
Level 5	13

Technologies Used

To make the web application's frond-end jQuery, Javascript and Bootstrap were used, while node.js and Heroku's postgreSQL extension were used for the back-end and the database. The application is deployed on Heroku.

Results and Data Analysis

In total 38 people participated in our experiment, and played 276 rounds of the 1 minute memorization game.

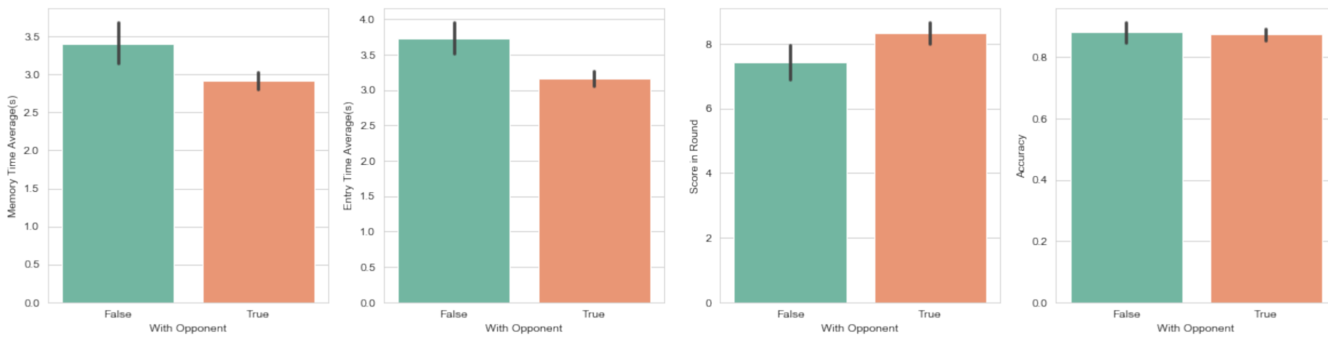

Figure 2: Comparison of from left to right Average Memorization Time(p -value = 0.000311, with_opponent = 2.91, without_opponent = 3.40), Average Entry Time(p-value = 4.18e-7, with_opponent = 3.15, without_opponent = 3.73), Score in Round(p-value = 0.00525, with_opponent = 8.32, without_opponent = 7.43), and accuracy (p-value = 0.703, with_opponent = 0.87, without_opponent = 0.88).

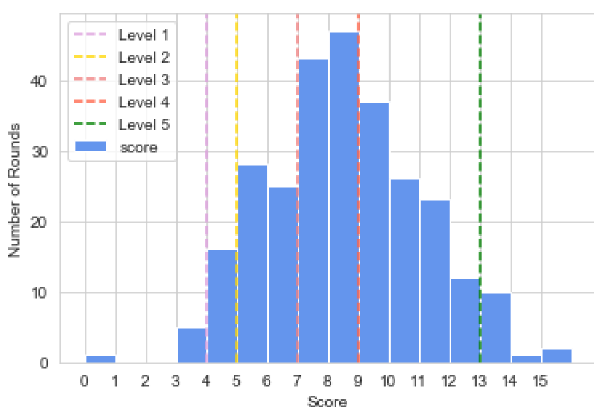

Figure 3: Histogram of all scores achieved by participants. Opponent levels are marked with dashed lines.

Figure 2 shows a detailed analysis of participant performance and how it has been affected by the addition of a competitive agent. The average score had a statistically significant increase with addition of opponent. It can also be seen that the average memorization time and the average entry time (time participants take to input their memorized number) has showed a significant decrease when the opponent was added.They both decrease by almost a 0.5 seconds. Average accuracy, on the other hand, did not have a statistically significant change. We see that we can account the change in increased score to solely on the decreased memorization and the entry time.

Figure 3, given above shows a histogram of all participant scores along with the markings of expected opponent scores that were also given in Table 1. This data includes the rounds both with and without opponent. Opponent with Level 5 difficulty was deliberately made very difficult so that we could observe whether there would be a significant performance increase due to participants pushing their cognitive limits. We saw that the average performance of a human was between the Level 3 and the Level 4 opponents with a mean of 8.01 points per round. Level 2 and Level 1 opponents were easy to defeat, and we speculate that the results less then them were gotten as a result of participants giving up on the game or getting distracted by some external factors.

Figure 4 shows the distributions of memorization times for different difficulty levels. One can see that the mode of the Level 4 curve is further on the left while Level 5 is the curve with the rightmost mode. Additionally, Level 3 curve has a noticeably higher peak value than the other distributions.

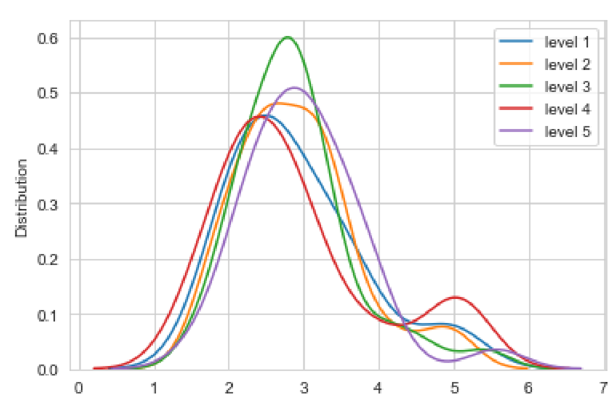

Figure 4: Distribution of average memorization time with different levels of opponent.

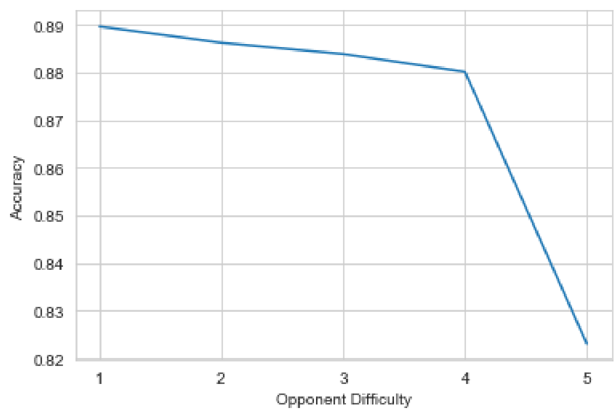

Figure 5: Distribution of average memorization time with different levels of opponent.

Finally, Figure 5 shows the average accuracy values at different levels of opponent difficulty. One can see a slight linear decrease in average accuracy as the opponent level increases from Level 1 to Level 4. For Level 5 opponent difficulty, on the the other hand, we can see a very sharp decrease in average accuracy from 0.88 to 0.823.

Discussion

Our experimental results show that average memorization time and entry time significantly decreased with the addition of a competing agent. We have found that Level 3 difficulty yielded both the shortest average memorization time (2.877 seconds) and the shortest average entry time (3.103 seconds). Even though, in Figure 4, one can see that Level 4 difficulty has the leftmost peak, it also has a peak around 5 seconds bringing the mean value down. We speculate that this peak around 5 seconds is caused by some participants finding Level 4 difficulty too difficult to defeat and giving up on competing.

Similarly, we can observe that Level 5 difficulty has the longest average memorization time (3 seconds) and the longest average entry time (3.241 seconds). Furthermore, in Figure 5, we observed a statistically significant decrease in average accuracy at Level 5. With an increased time and decreased accuracy, participants' overall average score has significantly decreased against Level 5 opponents (Level 5 average score = 7.366, Levels 1-4 average score = 8.517). As mentioned earlier, Level 5 difficulty was deliberately made very difficult to see whether it would significantly boost participant performance or create a detrimental effect. With our results, we can clearly conclude that addition of overly challenging opponents has negative effects on human cognitive performance.

Table 2: Scores that beat the opponent with 80% probability

Opponent Difficulty	Score to Beat
Level 1	5.164
Level 2	6.899
Level 3	7.650
Level 4	10.016
Level 5	13.079

After performing some probabilistic analyses on the distributions of opponent scores, we constructed Table 2, which shows the required scores to beat each level of opponent with an 80% probability.

The required score to beat with 80% probability was 5.164 for Level 1 and 6.899 for Level 2. Even though most participants could easily pass both levels, we saw that participants put slightly more effort into Level 1. So when both of the levels were easy to pass, participants didn't slack off while playing with the easier opponent, instead they put more effort into it. This might have been caused by a desire to do significantly better than the opponent. So when getting more points doesn't require a lot of additional cognitive effort, participants still cared about how much better they were doing than the opponent. Before the experiment we expected to see a decrease in effort when they were playing with the easier opponents, since we hypothesized that the participants would try to put in just enough effort to pass the opponent. However, we see that this wasn't the case. People not only care about if they beat the opponent, but they also care about by how much.

Furthermore, we can see that the score required to beat Level 3 opponent is very slightly above the average human performance without an opponent (7.43 given in Figure 2). Considering that participant performance playing against a Level 3 opponent was higher than their performance against Levels 2 and 4, we can conclude that their scores increased when they played against opponents that were around or slightly above their average performances.

Putting these together, we came up with a simple mathematical model for extra effort participants put into the task for a given competitive level. This model attempts to represent extra cognitive effort as a function of the difference between prior cognitive effort (without an opponent) and the required cognitive effort to defeat the opponent with 80% [1] probability. In Figure 2, we showed that average participant score without an oppo-

[1] 80 was selected as the probability that fits the data best.

nent was 7.43, which we can take to be the prior average human performance. If we assume that score is a direct measure of the cognitive effort, we can define e as the extra cognitive effort that people put in against opponents and d as the difference between their prior effort and the effort that is required to beat an opponent with 80% probability. Based on our results with Level 5 difficulty, we know that there is also a maximum limit to extra cognitive effort that participants can put into this task. We define this parameter as e_{max} and estimate it as 1.11 based on our results.

$$e(d) \propto e_{max} - \alpha * |d|^2 + \beta * \max(0, d)^2$$

Here α is a constant that represents how much emphasis the participants put into beating the opponent when deciding how much extra effort they should put into the task and β is a constant that represents how much emphasis they put into the score discrepancy. We found that according to our data $\alpha = 0.065$ and $\beta = 0.15$. With these parameters, we plotted the behavior of our model in Figure 6 (labeled probabilistic approach) along with the participant data. As you can see, there is a good fit between blue and orange lines.

Another questions we can answer is how do the participants actually model the opponent during the game. Is their goal beating the average opponent score or are they concerned about how certain they are about beating the opponent? Instead of using the probabilistic 80% approach, we used the average opponent scores as the required scores to beat an opponent and plotted the green line in Figure 6. We saw that our function fits the approach where participants want to beat the opponent by a probability measure (80%). This also represents a strategy selection problem. Here we see that the participants are formulating a strategy to put in effort based on their estimated probability of beating the opponent. They select to put more effort in exchange with a higher certainty that they will beat the opponent.

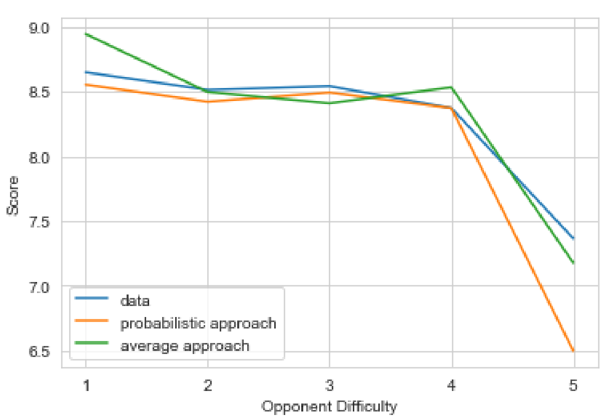

Figure 6: Comparing our model and data

In conclusion, this experiment has shown that average human cognitive performance on a simple number memorization game increases when competition is introduced. Further, we observed that, under certain assumptions, the extra cognitive effort that people put into this memorization task can be modeled as a function of the difference between their prior effort (effort that they put in without an opponent) and the anticipated effort that is required to defeat the opponent with some certainty.

Future Work

We got very promising and significant results from our experiment and there are different routes one can take to improve upon it.Even though we did not collect data on the demographic of our participants, we know that our participants were mostly young adults in their twenties. It would be interesting to see if the results would change with various demographics.

One improvement that that is related to experiment design is making who is winning and who is losing a lot more obvious during the game, perhaps by changing the background color slightly. Since the participants are currently focusing on the tasks, it might be slightly difficult to constantly notice what the opponent is doing. We could experiment with ways to make it even more noticeable and see if we would observe any changes in the data.

Currently our task is a number memorization game. We could include other types of tasks in future work that could also potentially force the participants to go through a time-accuracy trade-off. This could be achieved by making the task harder and by putting more cognitive load to the participants. Our number memorization game utilizes the short term memory and tasks that also involve long-term memory could be included in future work. One could also explore what happens when people play against each other in a room rather than playing against a computer. Offering a real price at the end of the game could also provide more accurate results for such a winner-takes-all game. We also saw that when people are faced with a very high level opponent, a popular response is to give up. We could dive deeper into explaining how people's projected cognitive effort relates to their estimation of the opponent level.

After implementing these improvements and conducting additional experiments, a more comprehensive analysis and modeling of the results can be achieved.

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