# Benchmarking Cognitive Abilities of the Brain with Computer Games

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September 5, 2018

#### Abstract

Most of the players have experienced the feeling of temporarily losing their character in a given gameplay situation when they cannot control the character, simply because they temporarily cannot see it. The main reasons for this feeling may be due to the interplay of the following factors: (1) the visual complexity of the game is unexpectedly increased compared with the previous time period as more and more game objects and effects are rendered on the display; (2) and/or the game is lagging; (3) and finally, it is also possible that the players have no sufficient experience with controlling the character. This paper focuses on the first reason. We have developed a benchmark program which allows its user to experience the feeling of losing character. While the user can control the character well the benchmark program will increase the visual complexity of the display. Otherwise, if the user lost the character then the program will decrease the complexity until the user will find the character again, and so on. The complexity is measured based on the number of changed pixels between two consecutive display images. Our measurements show that the average of bit per second values of losing and finding pairs describes the user well. The final goal of this research is to further develop our benchmark to a standard psychological test.

**Keywords**: esport, talent search, benchmark program, complexity, psychology test.

## 1 Introduction

Losing the control of the character in a given gameplay situation is a very common feeling that is well known among gamers. In this situation, players cannot control their character, simply because they temporarily cannot see it due to the visual complexity of the display is unexpectedly increased and/or



Figure 1: A screenshot of BrainB Test Series 6 in action. Can you find the box labelled by the name Samu Entropy in this picture?

the game is lagging and, finally, it is also possible that the players have no sufficient experience to control the character. In this paper, we introduce our benchmark computer program called *BrainB Test Series* 6 that can abstract this feeling. In this test, game objects are symbolized by boxes as it can be seen in Fig 1. All boxes move according to random walks. There is a distinguished box labelled by the name *Samu Entropy*. It represents the character controlled by the player. The benchmark test lasts for 10 minutes. During the test, the user must continuously hold and drag the mouse button on the center of Samu Entropy. If the user succeeds in this task then the benchmark program will increase the visual complexity of the display. It will draw more and more overlapping boxes which will move faster and faster. Otherwise, if the mouse pointer cannot follow the center of Samu Entropy then the visual complexity will be decreased. The test will delete more and more boxes and the remaining boxes move slower and slower until the user finds Samu Entropy again, i.e., clicks on Samu Entropy.

The BrainB Series 1 to 4 were developed in the family setting of the first author<sup>1</sup>. Then, in our university environment, we had already done a preliminary study  $[BBP^{+}18]$  on a previous (BrainB Series 5) version of our benchmark. Some of its measurements were streamed live on Twitch<sup>2</sup>. The main research goal of this study is to show that players lose the character on a higher complexity level of the display and they find it on a relatively lower complexity level.

The organization of the paper is the following. In the next section, we give a brief overview of the psychological and informatics background and the phenomenon of losing the character is illustrated. The second section presents the algorithm and the operation of our benchmark program including the presentation of the first measurements followed by systematic measurements. Finally, we conclude our paper and show some future plans.

<sup>&</sup>lt;sup>1</sup>For example, see https://www.twitch.tv/videos/139186614

<sup>&</sup>lt;sup>2</sup>For example, see https://www.twitch.tv/videos/206478952

#### 1.1 Psychological Background

The cognitive ability of attention is a significant factor in everyday life, either it comes from work, hobby or the daily activities, as it affects the performance of all the previously mentioned things. The alertness, or in other words, the long upheld attention, in technical terms is called vigilance. The research of vigilance is an important topic in Psychology from 1970 to the present day. The first method used was the Mackworth Clock [Mac48], in which the participants had to pay attention to a clock that had a second hand which sometimes sprang twice, and then the participants had to signal as soon as possible. For measuring attention and concentration, there is another method, the Toulouse-Piéron test [TP13], in which participants have to follow a given scheme to separate right and wrong signs. To measure vigilance we must take into consideration the hit ratio and the number of false alarms. In almost all of our activities there are also interfering stimuli that affects our performance as well. These other factors vary by quantity and quality, and some can be stimulating, while some detain us from the optimal performance. The Yerkes-Dodson law [YD08] says that for achieving the best performance there is an optimal arousal level, which level is higher in simpler tasks, and lower in complex activities. It can be represented by a inverted U-shaped curve. We must not forget that as in some other things, in the attentional system there are also personal differences that should be taken into consideration while researching the subject [CGR07].

Other objects in the environment can affect how we perceive the one object that is interesting for us. In 1940, Witkin et al. did a research on perception [WLH<sup>+</sup>54], and from this work, they created a theory about two different cognitive styles, which they called field dependent, and field independent. A field dependent person perception is mainly affected by the field, the environment of the observed object. On the contrary, a field independent person does not affected by the field created by the observed object's environment. This phenomenon was investigated by a task, in which the participants had to determine whether a straight rod, in different planes is vertical or not. Moreover, there is another typical method used in this topic, that is the Tilting room, Tilting chair test, in which the participant is sitting in a tiltable chair that he or she needs to controll in order to get him/herself into vertical position despite the tilting room. Later, Witkin and Goodenough reinvestigated the topic, and they came to a conclusion that the two styles are two ends of the spectrum, however, some people are fixed with one of the cognitive styles, while others can adapt to the style they use depending on the situation [AWRG76].

Speaking of attention, it's important to talk about the main processing system, i.e., the brain. The operation of the brain is frequently compared to the mechanism of a personal computer by many researchers. Carl Sagan based his theory on the binary coding, so he used the information content in binary. When we are watching something, the picture seen that our brain maps, is made of plenty of information. Sagan wanted to calculate the information processing speed of the brain, to do so, he based his calculation on the example of looking at the moon, and from this example he drew the consequence, that the brain can process about 5000 bit/sec at its peak performance [Sag12]. In a modern project, called Building 8, the main thought is to make the brain into a computer. Based on this project, the information processing speed of the brain is about a terrabyte/sec, which far exceeds the speed estimated by Sagan [Nie17].

#### 1.1.1 Practicing filling out tests

Filling out tests and experiments are common tools in the science of psychology. Countless methods were created to date, but these methods are not just used, because researchers improve them, as well as, try to test them in a wider range. However, we need to consider certain factors in each experiment and test that how they affect the method's usability and the final results as well. Among these factors, there is one, when the participant obtains knowledge about what is expected from her/him, or which answer are considered the 'best'. This way the participant will accomodate to this information, because he/she, as everyone else, wants to portray herself/himself in the best manner possible and to be the 'best' in performance. In multiple choice questions, there are some tricks, that are well known in the common knowledge, which we all use, when we don't know the right answer for sure. A somewhat similar tool is the experience or routine with filling out tests, which can help to choose the adequate strategy for solving the situation, this is called test-wisdom. To achieve that, one must discover the logic behind the method, or practise it many times. But the test-wisdom often cause inconvenience for test developers, because they have to keep in mind a bonus factor, which is totally diverge from the basic variables they meant to manipulate, and vary in each individual [RSA06].

The effect of being experienced in filling in tests was studied in a research, in which an aptitude test called GRE (Grand Record Examination) was used. Practise samples were sent to random participants 5 weeks before the examination. Those who got these samples also received advices for completing. In conclusion, the group with prior knowledge and practise earned significantly better results in the examination. Furthermore, there were also a notable growth in points, when the participants received an only 4 hours educational practise before the examination. It's important to note that this difference and growth was present only in the logical reasoning part of the exam, and not in the mathematical and verbal parts [PS84]. This data was reexamined later, because researchers wanted to know, if there is any difference when the existing groups would be split into subgroups by the difference between the subgroups, but there was a notable difference in the group in which the members' primary language was not English, they scored lesser points than the others [Pow86].

Repeatedly performing the same experiment or test with the same participants could affect the results. Previously, as we specified, repeatedly using the same method could cause the lowering of its validity, and the results could be distorted. Participants can learn and adapt to certain methods, even if its just means a small percentage of difference. The current test takes 10 minutes to complete, in this 10 minutes the participant's full attention and concentration is needed. We should keep in mind, that the negative effects of fatigue could balance the positive effects of practise, in a direct way of repeated examinations. So this two factors should be considered in the evaluation, and while drawing consequence.

It is therefore proposed to perform our benchmark test in a competitive way trying to beat friends, family members, colleagues or ourselves.

#### 1.2 Informatics Background

Since computer games have a relatively short history and their effects on cognitive skills have just been started to be researched recently, there are plenty of questions to be answered. In [HPR<sup>+</sup>18], authors reported an increase in executive functions in school students after playing computer games. Moisala et al. in [MSH<sup>+</sup>17] shows that enhancements in speed and performance accuracy of working memory tasks is related to daily gaming activity. In [BAM<sup>+</sup>18], authors present an analysis of the impact of action video games on cognitive skills.

Using computer games to measure cognitive abilities has a short history, but a promising future. Most research try to measure the presence or severity of a certain cognitive disease such as dementia or Alzheimer's disease. In [ABR<sup>+</sup>13], authors show how a long-term use of video games can reduce multitasking costs in older adults. Geyer et al. in [GIF<sup>+</sup>15] show that the change of the score of an online game is in connection with the age-related changes in working memory.

Seldom can we find applications that has been developed for the measurement of cognitive abilities. One such application is reported in [PHC15b] and [PHC15a], it is a framework that has been developed to measure cognitive abilities and its change of elders with computer games. This framework is able to log and analyze scores achieved in various online computer games.

From the viewpoint of information theory and HCI (Human-Computer Interaction), the Hick's law [Seo05] could be an interesting aspect. This law states that the response time of the brain increases with logarithm of the size of the input. For our purposes, it can be an interesting question: how can we apply the Hick's law (or other information theory figure) in our benchmark software?

#### 1.3 Losing The Character

We have experienced the feeling of losing the character during playing several games like for example League of Legends<sup>3</sup>, Clash of Clans<sup>4</sup>, Clash Royale<sup>5</sup>, Heroes of the Storm<sup>6</sup>, Dota 2<sup>7</sup>, World of Warcraft<sup>8</sup> or Cabal<sup>9</sup>.

Now we share our thoughts about the phenomenon of ,,losing the character", and give some examples to illustrate it from the game called League of Legends. Basically, a match starts kind of slowly and quietly: the laners are farming, as well as the junglers in their own territory. Of course smaller fights can occur in the early stages of the game, like a 1v1 in the solo lanes, or a 3v3 in the bottom lane as both of the junglers decides to gank, but these situations are relatively easy to see through. As we head into the mid and late game, teams start fights more often with more people, even with all of them. This is what we call teamfights. These are harder to handle, because a lot of things can appear on our screen at the same time: the champions who participate in the fight, optionally minions or jungle monsters, and the visual effects of the spells, summoner spells, and the active or passive abilities of the items. Besides them,

<sup>&</sup>lt;sup>3</sup>https://na.leagueoflegends.com

<sup>&</sup>lt;sup>4</sup>http://supercell.com/en/games/clashofclans/

<sup>&</sup>lt;sup>5</sup>http://supercell.com/en/games/clashroyale/

 $<sup>^{6}</sup>$ https://heroesofthestorm.com

<sup>&</sup>lt;sup>7</sup>https://www.dota2.com

<sup>&</sup>lt;sup>8</sup>https://worldofwarcraft.com

<sup>&</sup>lt;sup>9</sup>http://cabal.playthisgame.com

we see a lot of things, we still have to make sure that we fulfill our ingame role properly: position well, attack the proper target, or defend our teammates. We have to handle a lot of information at a blink of an eye, so it is completely natural, that sometimes we do not know where to look at or what to do. We can lose our own character, which can end with our death; we can lose the target character, and it can survive; or we can lose the character that we wanted to protect, thus an important member of the team can die. This can be a short explanation of the phenomenon, which we can also call "losing the focus".

An example ingame footage can be viewed at https://youtu.be/wdy3KUm1454, starting at 2:12.

These situations are one of the hardest parts of the game, and it is not easy to handle them well. The easiest way to prepare for them is to play a lot of games, and get experience in them. Also it can help a lot, if we think ahead before a potential teamfight, e.g. which character will be our target, who should we be afraid of, what summoner spells the enemy still has, etc. All of these things can help to execute the fights more properly.

## 2 Brain Benchmarking Series 6

BrainB is a Qt C++ desktop application that uses the OpenCV library. It is developed as an open source project that is available on GitHub [B17]. Its source can be built easily on GNU/Linux systems. But the latest (6.0.3) Windows binary release can also be downloaded as a ZIP file from http://smartcity. inf.unideb.hu/~norbi/BrainBSeries6/.

It is important to show the algorithm of BrainB as precise as possible because the randomness plays a key role in its operation due to boxes doing random walks. The code snippet shown in Listing 1 is the heart of our benchmark program. It is a simplified version of the original source code that can be found in the GitHub repository at https://github.com/nbatfai/esport-talentsearch/blob/master/BrainBWin.cpp#L65. This code is executed at every 100 milliseconds that is ten times per second. First, as shown in Line 1, it computes the distance between the mouse pointer and the center of the box of Samu Entropy and the result is stored in the variable called *dist* that holds the square of the Euclidean distance. If the distance is larger than 121 pixels (11 is the square root of 121) and if it reoccurs 12 consecutive times or more in a row (that means at least a time interval of 1.2 seconds) and it is also true that the player was controlling the character well in the previous time slices (that is in Line 10the state is equal to found) then we say that the user has lost the character Samu Entropy and the visual complexity of the display will be saved in Line 12. The sequence of these losing values and the symmetrical finding values saved in Line 28 are shown in Fig 2. The complexity is computed in bits per second (bps) units that is based on the number of changed pixels between two consecutive rectangular environments of the character with a given width and height.

Listing 1: The algorithm for administration of losing and finding the character.

```
1 int dist = ( this->mouse_x - x ) * ( this->mouse_x - x )
2 + ( this->mouse_y - y ) * ( this->mouse_y - y );
3
4 if ( dist > 121 )
5 {
6 ++nofLost;
```

```
nofFound = 0;
7
8
      if ( nofLost > 12 )
9
         {
10
           if
             ( state == found && firstLost )
11
             {
12
               found2lost.push_back(brainBThread->get_bps());
13
             3
           firstLost = true:
14
          state = lost;
nofLost = 0;
15
16
17
           brainBThread ->decComp();
18
        7
   }
19
20 \text{ else}
21
   {
22
      ++nofFound;
23
      nofLost = 0;
      if ( nofFound > 12 )
24
25
         {
26
           if ( state == lost && firstLost )
27
             ſ
28
               lost2found.push_back(brainBThread->get_bps());
29
             }
30
           state = found;
           nofFound = 0;
31
32
           brainBThread ->incComp();
33
        }
   7
34
```

The final result printed by the benchmark after it ends in the form "U R about 5.92902 Kilobytes" is the mean of upper bounds for the bps values of the display measured when the variable state changes from found to lost (in Listing 1 from Line 10 to 14) and vice versa, when the variable state changes from lost to found (in Listing 1 from Lines 26 to 30). The simple calculation of this final result is shown in Listing 2.

Listing 2: The calculation of the final result of the benchmark that is produced in a text file that is saved in the folder where the benchmark was started.

```
1 int m1 = mean ( lost2found );
2 int m2 = mean ( found2lost );
3
4 double res = ( ( ( ( double ) m1
5      + ( double ) m2 ) /2.0 ) /8.0 ) /1024.0;
6
7 textStream << "U<sub>u</sub>R<sub>u</sub>about<sub>u</sub>" << res << "<sub>u</sub>Kilobytes\n";
```

### 2.1 First Measurements

As concluded in our former preliminary study [BBP<sup>+</sup>18], one of the further developments of Series 5 is changing to full screen from fixed-size window. This modification affects the basic operation of the benchmark, so the first objective was to verify that whether the feeling of losing the character still appears correctly or not. On Windows systems there were no problems. Some experiments using default settings on Windows 10 can be seen in Fig 3, Fig 4 and Fig 5. But on GNU/Linux systems test subjects reported that the feeling of losing the character is not experienced. These observations will be detailed in a next section.

## 2.2 Logging Data

The state of the BrainB benchmark can be saved at any time by pressing the S button but measured data is automatically saved after the test is finished. The



Figure 2: The bps values associated to events of losing and finding. The first element of this sequence is the first element of the *lost2found* (shown in Listing 1 Line 10) sequence. The second element is the first element of the *found2lost*, and so on. It should be noticed that the losing (labelled by L) and finding (F) events are mixed, see, for example the 13th event on the x axis where the complexity of finding is greather than the complexity of losing in this individual measurement. This test was performed by the first author (46 years old, on a Dell XPS 9333 ultrabook with Windows 10 using the touchpad, resolution 1920x1080, scale 150%). The final result was 5.92902 Kilobytes. All the logged data can be found at http://smartcity.inf.unideb.hu/~norbi/BrainBSeries6/measurements/NB/. Fig 1 shows the last screenshot of this experiment.



(c) The final result was 5.45563 Kilobytes.

(d) The final result was 6.37927 Kilobytes.

Figure 3: These tests were also performed by the first author on the same environment as in Fig 2. All the logged data and final screenshots can be found at http://smartcity.inf.unideb.hu/~norbi/BrainBSeries6/measurements/NB/.



(a) 6.51813 Kilobytes (performed with the touchpad).

(b) 4.31812 Kilobytes (performed with a mouse).



(c) 6.79218 Kilobytes (performed with the touchpad).

Figure 4: This test was performed with a male child (10 years old, on the same environment as in Fig 2). The data and final screenshots can be found at http://smartcity.inf.unideb.hu/~norbi/BrainBSeries6/measurements/NaB/. It should be noted that test subjects with touchpad can use both hands, one for holding the button and the other for motion.





(a) This final screenshot corresponds to Fig 4a.

(b) This final screenshot corresponds to Fig 4b.



(c) This final screenshot corresponds to Fig 4c.

Figure 5: This test was performed with a male child (10 years old, on the same environment as in Fig 2). The data and final screenshots can be found at http://smartcity.inf.unideb.hu/~norbi/BrainBSeries6/measurements/NaB/.

program saves a screenshot of the display to a PNG file. For example, such a screenshot was shown in Fig 1. The data is saved to a text file that contains the information shown in Listing 3, where the most important lines are the following. The two time values tell the time when data is saved. The first one (in Line 2) is expressed in 100 millisecond units and the second one (in Line 48) is expressed in the form minutes:seconds. The noc value tells the number of characters (boxes). The nop value tells the number of pause events initiated by the test subject. The relation symbol in Line 47 indicates the fulfillment of our research hypothesis that the mean of the complexity of changing from lost to found is less than the mean of the changing found to lost.

Listing 3: The structure of the measured data. This log file is belong to the measurement shown in Fig 3d.

```
NEMESPOR BrainB Test 6.0.3
                 6000
^{2}_{3}
   time
   bps
                 28170
4
   noc
                 71
5
                 0
   nop
6
   lost
7
   30530 31840
                 39910
                       10960
                              60270
                                     71280
                                            50340
                                                  51580
                                                         31670
8
   49260
          53710
                 41620
                        86830
                              72580
                                     56310
                                            70560
                                                   68870
                                                         45500
9
   52480
          52660
                 45640
                        46870
                              44660
                                     75860
                                            68150
                                                   70110
                                                          69610
10
   47130
          61980
                 75310
                        90440
                              75700
                                     62670
                                            54870
                                                   69820
                                                         75170
                              54920
                                                         28860
11
   84350
          76990
                 80480
                        70840
                                     40720
                                            33800
                                                  31590
12
                 53490
                                     57490
                                                  39030
   24650
          27250
                       58180
                              56200
                                            53930
                                                         83870
13
   87180
          78270
                 70990
                        43600
                              52360
                                     43910
                                            33820
                                                  31120
                                                         34830
   32370
          32840
                 37080
                       32390
14
15
   mean
                 54181
16
   var
                 18541.5
17
   found
18
   12880
          22240 26690 11190 19880 36170 14930 28100 25860
```

```
19
   27580 36040 34590 22250 12060 11760 8880 10660 30840
20
    48000 33030
                 43040
                       26330
                              45880
                                    50380
                                           34970 45950
                                                        36610
21
    46660
          47980
                 45330
                       65290
                              57080
                                    55340
                                           54700
                                                  43930
                                                         34850
22
    55030
          43240
                       50770
                 69500
                              58680
                                     54750
                                            65470
                                                  59610
                                                         79030
23
    67190
          63890
                 61550
                       65590
                              54100
                                     69460
                                            69210
                                                  37390
                                                         41850
          31650
24
    53130
                 45400
                        46430
                              50490
                                            35960
                                                         25760
                                     44310
                                                  53510
25
    38950 33250
                 39360
                       46650
                              63050
                                     64890
                                           68590
                                                  76430
                                                         50570
26
    57630
          57250
                 28830
                       42020
                              45500
                                     67160
                                            63310
                                                  69930
                                                         80200
27
    76980
          56300
                       58340
                              79850
                                                  88200
                                                         89160
                 44320
                                    81590
                                            69740
28
   62640 55030
                 60510
                       39810
                              51660
                                    51730
                                           47720
                                                  62330
                                                         66150
29
    47100
          60470
                 70810
                       88930
                              75110
                                     65290
                                            68830
                                                  59430
                                                         63710
    22570
                       43630
30
          36940
                 29450
                              53100
                                    55560
                                            64750
                                                  39530
                                                         59610
31
    58250
          71950
                 62800
                       75250
                              76720
                                    81910
                                           31730
                                                  47010
                                                         44890
32
   58490 61750
                 66900
                       69380
                              81650
                                    79450
                                           72420
33
   mean
                 51442
34
                 18616
    var
35
                       22250 11760 43040 26330 34970 46660
    lost2found:
                 14930
36
    43930 50770
                 61550
                       54100 37390
                                    31650 44310
                                                  25760
                                                         50570
    28830 56300
                 69740
                       62640 39810 62330 65290 59430 22570
37
38
   39530 31730
                 72420
39
   mean
                 43235
40
                 16826.
   var
               :
    found2lost:
41
                 31840
                       10960 60270 51580 31670 49260 53710
42
    86830 70560
                 68870
                       45500 52660 45640 46870
                                                  75860 69610
43
    61980 75310
                90440 54870 69820 75170 84350 80480
                                                         53490
44
   56200 83870 78270
45
   mean
                 61283
46
                 18824.2
    var
                      < mean(found2lost)
47
   mean(lost2found)
48
                10:0
    time
   U R about 6.37927 Kilobytes
49
```

### 2.3 Choosing Colors

We put a lot of emphasis on what colors to choose for our benchmark. The reason for this is that even the standard test requires a constant focus of 10 minutes, which can put a lot of pressure on one's eyes. To ease this strain as much as we possibly could, we took lots of things into account. Firstly, we tried to maximize the contrast between the background and the figures. This means that we picked some colors that could be easily distinguished and then we ran some manual tests. The result was a significant drop in the overall burden of the eyes.

After this, we thought about how we could make the benchmark available for a wider range of people, namely for those who suffer from parachromatism or even disambiguation. This is rather important as it is said that roughly 8%of men and 0.5% of women<sup>10</sup> suffer from one of these. In order for them to be able to comfortably run our benchmark, we tried to pick colors that are easily distinguishable even for these people.

Another problem was that we did not target a specific age group. On the contrary, we were especially curious about the results of adults, adolescents, teenagers and children. Therefore, we needed to pick a color scheme that was modern, vivid, yet not too complex and not too abstract. This, too, required a lot of experimentation.

#### 2.4 Known Problems with Series 6

Despite that our benchmark is developed on Linux it is surprising that test subjects who performed it on Linux did not experience the feeling of losing

<sup>&</sup>lt;sup>10</sup>http://www.color-blindness.com/2006/04/28/colorblind-population

the character. This problem causes the deteriorated results shown in Fig 6. It is important to note that it has not been detected in earlier series of the application. Moreover, before Series 6, there was no Windows binary edition of BrainB program. In Series 6, changing to full screen from windowed causes the problem because Series 6 is sensitive to the different mouse sensitivity settings on Windows and Linux systems (the measurements shown in Fig 6 were performed with a Logitech mouse with *acceleration*: 5/1 and *threshold*: 5 xset m<sup>11</sup> setting). A short-term solution may be to standardize the test environment used by each member of a given subset of test subjects. We apply this method to perform systematic measurements with Series 6 in the next section. The long-term solution will be to fine-tune the control of movements of boxes that is hardwired into the Series 6 from Series 5 at this moment. Another possibility is to take the liberty of fine-tuning of the mouse for test subjects who thus would be able to choose their custom mouse settings in order to increase their effectiveness. This is also in well accordance with the competitive way of performing our test. Fig 7 presents two measurements using custom mouse settings.

#### 2.5 Systematic Measurements with Series 6

The BrainB Series 6 was measured in two groups: UDPROG and DEAC-Hackers. The first one is a Facebook community of over 550 actual or former students of the BSc course of "High Level Programming Languages" at the University of Debrecen. The second one is an esport department of the University of Debrecen's Athletic Club. Participation in the BrainB Series 6 survey was voluntary in both groups.

In the UDPROG community 33 members send back their results including the PNG screenshot and the produced text file within 2 days from the date of announcement (20 August 2018). The arithmetic mean of the final results of UDPROG participants is 4.95345. The mean of the number of boxes at the moment when the benchmark ends is 57.1818. The averaged losing and finding curve for all members is shown in Fig 8a. At the end of the curve the arithmetic mean values of complexity of the losing and finding events are irrelevant because the size of the sequences of losing and finding events are different for every participants. Fig 8b indicates these different sizes.

In the DEAC-Hackers community 12 esport athletes have sent back their results that can be seen in Fig 9. It is important to notice that despite low sample sizes of test subjects the averaged losing and finding curves shown in Fig 8a and 9a have already separated the losing and finding events.

## 3 Conclusion

Our research hypothesis was that the mean of the complexity of changing lost to found is less than the mean of the changing found to lost. Fig 8a and 9a show the fulfillment of this hypothesis. It seems very well in these figures that the averaged losing and finding curve has precisely separated the losing and finding events. Intuitively, this result shows that we lose the character on a higher complexity level then we find it on a relatively lower level again. This simple hypothesis has been proved by the results of this study.

<sup>&</sup>lt;sup>11</sup>https://www.x.org/archive/X11R7.7/doc/man/man1/xset.1.xhtml



(a) The test subject was the same as in the experiment shown in Fig 3. The final result was 3.76904 Kilobytes.



(c) This final screen shot corresponds to Fig  ${\bf 6a}.$ 

(b) The test subject was the same as in the experiment shown in Fig 4. The final result was 3.75116 Kilobytes.



(d) This final screenshot corresponds to Fig 6b.

Figure 6: These tests were performed on a GNU/Linux desktop (Ubuntu 16.04, SyncMaster S24B300 monitor with resolution 1920x1080). Test subjects reported that the feeling of losing the character is not experienced.



(a) The final result was 5.95587 Kilobytes. xinput settings were the following "Device Accel Constant Deceleration (277): 1.000000", "Device Accel Velocity Scaling (279): 1.000000" and "Device Accel Profile (276): -1"



(c) This final screen shot corresponds to Fig  $7 a. \label{eq:correspondence}$ 

(b) The final result was 5.71674 Kilobytes. xinput settings were the following "Device Accel Constant Deceleration (277): 2.000000", "Device Accel Velocity Scaling (279): 15.000000" and "Device Accel Profile (276): -1"



(d) This final screenshot corresponds to Fig 7b.

Figure 7: The test subject was the same as in the experiment shown in Fig 3. The subject reported that the feeling of losing the character has already been experienced.



(a) This figure shows the averaged losing and finding curve for all UDPROG participants where the losing (L) and finding (F) events are also indicated.

(b) The sizes of samples of losing and finding events. The x-axis shows the sizes and the y-axis shows the number of test-subjects.

Figure 8: Measurements in the community UDPROG. The arithmetic mean of the final results of UDPROG participants is 4.95345. The mean of the number of boxes at the moment when the benchmark ends is 57.1818. The anonymized data can be found at http://smartcity.inf.unideb.hu/~norbi/BrainBSeries6/measurements/UDPROG/.



(a) This figure shows the averaged losing and finding curve for all DEAC-Hackers participants where the losing (L) and finding (F) events are also indicated.

(b) The sizes of samples of losing and finding events. The x-axis shows the sizes and the y-axis shows the number of test-subjects.

Figure 9: Measurements in the community DEAC-Hackers. The arithmetic mean of the final results of DEAC-Hackers participants is 3.71036. It is surprisingly lower than expected if compared to the value 4.95345 of the examined programming community. The mean of the number of boxes at the moment when the benchmark ends is 49. The anonymized data can be found at http://smartcity.inf.unideb.hu/~norbi/BrainBSeries6/measurements/DEACH/.

In order to further strengthen the completion of our benchmark test in a competitive way in the following versions we are going to offer to test subjects a little more liberty of fine-tuning the settings. The fine-tuning of mouse settings was already mentioned earlier. A further possibility is to allow using custom colors.

The next research objective will be to verify the satisfaction of Hick's law. To achieve this goal it is simple enough to compare the complexity of finding and losing events with the time differences of these. Unfortunately, the actual version of the BrainB benchmark do not record these timestamps. The BrainB Series 7 will contain this feature. Our long-term research goal is to further develop our benchmark to a standard psychological test that can be used for talent search in esport.

## 4 Acknowledgement

Thanks to the students of the BSc course titled "High Level Programming Languages" at the University of Debrecen, to the members of the NEMES-POR mailing lists https://groups.google.com/forum/#!members/nemespor, to the members of the UDPROG Facebook community https://www.facebook. com/groups/udprog and to the members of the DEAC-Hackers esport department http://deac.hu/szakosztalyok/esport for their interest and for performing the BrainB Test Series 6. Special thanks to Renátó Besenczi for pretesting the Windows release of the BrainB program, to Roland Paszerbovics, Gergő Hajzer and Péter Rozsos for their interest and support and to Nándor Benjámin Bátfai for performing the BrainB Test Series 6 on several occasions.

Finally, our thanks go to Dr. Péter Jeszenszky for reading the manuscript and suggesting improvements.

Author contributions were the following: N. B.<sup>12</sup> conceived the idea, developed the benchmark program, collected the data from the UDPROG community and analyzed the measurements. D. P.<sup>13</sup> wrote the section "Psychological Background". G. B.<sup>12</sup> wrote the section "Choosing colors". R. B.<sup>12</sup> wrote the section "Informatics Background" and collected the data from the DEAC-Hackers. D. V.<sup>12</sup> wrote the section "Losing the Character". All authors edited and reviewed the final version of the manuscript.

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<sup>&</sup>lt;sup>12</sup>This work was supported by the construction EFOP-3.6.3-VEKOP-16-2017-00002. The project was co-financed by the Hungarian Government and the European Social Fund.

<sup>&</sup>lt;sup>13</sup>The work/publication is supported by the GINOP-2.3.2-15-2016-00062 project.

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