Assessing Memory Colors of University Students

Cecilia Sik-Lanyi, Bence Halmosi, Jinat Ara, Judit Szűcs and Tibor Guzsvinecz

Abstract—**Human perception is complex, and can be influenced by several factors. The study's purpose is to understand these factors, thus, an application was developed. This application examines memory colors in the CIELAB color space. Memory colors can be affected by nationality, virtual reality game playtime, and the presence or absence of an image cue. The memory colors of banana and orange had the highest agreement between the students, while the memory colors of river and grass had the largest dispersion. Virtual reality games influenced the memory color of grass the most. It can also be concluded that without an image cue, different colors were selected in 70.90% of the cases.**

Index Terms—**cognitive aspects of virtual reality, cognitive infocommunications, color perception, cross-cultural study, human-computer interaction, memory color, virtual reality.**

I. Introduction

THE electromagnetic radiation that reaches our eye and produces sensations is called color stimulus. Consequently, this sensation produces the perception of colors in our brain. Three components of color perception are distinguished in the scientific literature: brightness, hue and colorfulness [1]:

- Brightness: the sensation can be almost blinding strong, medium or dim and dark;
- Hue is usually shown as a hue circle, where four distinguishable different areas are red, yellow, green and blue. A yellow hue can be reddish or greenish, but can never be bluish; a green hue can be yellowish or bluish, but can never be reddish, and so on [2]. It is possible to define the hues between two fundamental (or unique) hue, as e.g. green, bluish green, greenish blue, blue. Sometimes for the hues that are somewhere in the middle between two unique hues special names is used:
    a. Yellow – red: orange
    b. Green – yellow: lemon
    c. Blue – green: cyan or turquoise
    d. Red – blue: magenta or purple
- Colorfulness has been divided by MacDonald into a five-value scale: Starting with gray (achromatic) up to the most brilliant color. If no hue can be determined for a color then it is gray (or white or black). Thus, with increasing colorfulness one can speak about a gray, grayish, moderately vivid, vivid and very vivid color perception.

Therefore, for example, the communication of color perception can be made in the following form: the person's complexion who stands in front of us is medium bright, moderately vivid and reddish yellow [3].

However, as computer scientists, the human visual system can be described as follows: visual perception is the act of observing patterns and objects through vision or visual input. At the highest level, vision systems are almost the same for humans, animals, and most living organisms. They consist of a sensor that captures an image and a brain that processes and interprets an image [4]. Then, it outputs a prediction based on the data extracted from the input image, as shown in Figs. 1 and 2. In other words, the human visual system perceives depth through a sequential process involving the analysis of color, motion, form, and ultimately, the construction of a three-dimensional perception of the visual scene.

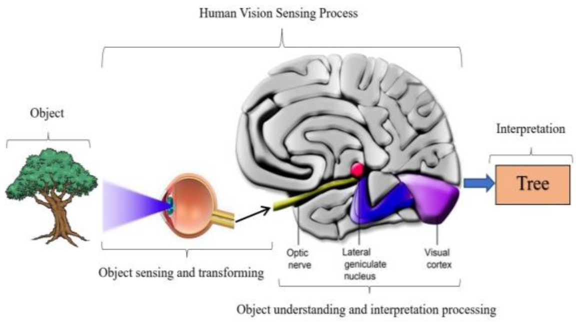

Fig. 1. The human vision system

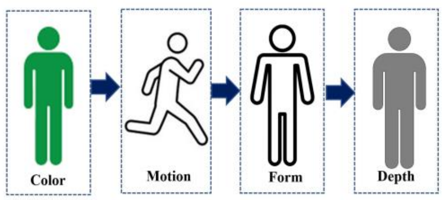

Fig. 2. How depth is formed.

Submitted on 7/1/2023
Cecilia Sik-Lanyi is with the Department of Electrical Engineering and Information Systems, Faculty of Information Technology, University of Pannonia, Veszprem, Hungary (e-mail: lanyi.cecilia@mik.uni-pannon.hu). She is the corresponding author.
Bence Halmosi is with the Department of Electrical Engineering and Information Systems, Faculty of Information Technology, University of Pannonia, Veszprem, Hungary (e-mail: halmosi.bence@mik.uni-pannon.hu).
Jinat Ara is with the Department of Electrical Engineering and Information Systems, Faculty of Information Technology, University of Pannonia, Veszprem, Hungary (e-mail: jinat.ara@mik.uni-pannon.hu).
Judit Szűcs is with the Department of Information Technology and its Applications, Faculty of Information Technology, University of Pannonia, Zalaegerszeg, Hungary (e-mail: szucs.judit@zek.uni-pannon.hu).
Tibor Guzsvinecz is with the Department of Information Technology and its Applications, Faculty of Information Technology, University of Pannonia, Zalaegerszeg, Hungary (e-mail: guzsvinecz.tibor@zek.uni-pannon.hu).

DOI: 10.36244/ICJ.2024.5.3

A memory color is the general color of an object that we recall due to our experience with it. For instance, most individuals are aware that ripe bananas are yellow in color. Our ability to consistently replicate an object's color in our minds increases with frequency of exposure [5]. However, memory color does not always match the original color. According to research, these colors are stored by the brain as being brighter and more saturated than the colors of the actual objects. This is most likely a result of the fact that our brains store them as the most aesthetically pleasing colors of an object. Although there are undoubtedly differences between people in terms of memory colors, the majority of us share a common memory color for everyday objects like the human face or other natural objects [6].

Lightness, chroma, and hue shifts can be observed in short-term memory, and neither sensory mechanisms nor differences in adaptation can account for these shifts [7-10]. These shifts can be explained by the cognitive effect hypothesis as an exaggeration. Focal colors, prototypical colors, and color regions have various effects on color perception. This results in various degrees of color memory shifts [11]. As can be seen, the previously mentioned phenomena and effects are cognitive. If we want to assess these in the digital world, the Cognitive InfoCommunications (CogInfoCom) field of research provides the perfect toolkit for this study. CogInfoCom is an interdisciplinary field that examines the relationship between human, information, and communication technologies [12-15]. Thus, it gives an opportunity to investigate several human factors using modern cognitive IT methods. Among others, human-computer interaction as well as human vision are investigated in the field of CogInfoCom [16-21].

Thus, the purpose of this article is to investigate the influence of various factors, including nationality, virtual reality (VR) game playtime, and the presence or absence of image cues on memory colors within the CIELAB color space. By examining the impact of these factors on the perception of memory colors, the study aims to contribute to a deeper understanding of human perception and its practical implications, particularly in the context of virtual environments and color cognition.

In order to present this pilot study, this article is structured as follows. Section II presents related studies. The materials and methods are shown in section III. The results are detailed in section IV, while they are discussed in section V. Conclusions are drawn in section VI.

II. Related studies

There are numerous studies on the subject of memory colors. Bartleson tested 50 participants to find the memory color for 10 everyday objects using the Munsell color scale, which consists of hue, value, and chroma. The conclusion drawn from researching ellipses is that there is some consistency in color choice. This implies that the hues are not noticeably different. After taking hue and saturation into account, he came to the conclusion that two-thirds of the color selections were 2.44 patches apart at most [6]. In a study from 2006, participants were asked to change the hue of several fruits so that they would appear grayscale. When the fruit's original hue was changed to the opposite color, the subjects thought it was gray. For instance, to make bananas appear gray, subjects gave them a blueish shade (which is the opposite of yellow) [22]. These findings show that visual memory has a significant impact on how color is formed in our brain that it is not entirely based on the perceived information [23].

Studies have also revealed that the colors used in virtual reality video games frequently differ from those that may be observed in the real world, for instance, the grass in certain games is significantly darker [24]. Another investigation into memory colors was done in 2009. Sik-Lanyi determined that virtual reality video game addicts associated darker green color with grass [25]. Nationality-related research was conducted by Tarczali, although only the memory colors of Korean and Hungarian testers were compared [26]. According to the study's findings, "the effect of a visual cue on memory plays a significant role in the study of color shifts, and its presence or absence can alter memory in different ways throughout observation" [27]. A study on the impact of culture on long-term memory span was carried out in 2014 in seven countries (Belgium, Brazil, Colombia, China, Hungary, Iran, and Taiwan). On a calibrated monitor, individuals in each country were shown every-day objects in more than 100 different colors. The testers were tasked to judge whether an object resembled the original object when they saw it in a particular color. According to statistical analysis, the averages of countries and the averages of all exams were significantly different [28].

A test software was developed to test the memory colors associated with brands [29]. In this software, participants had to color logos of brands. The results show that if participants had to remember more colors, they had selected more wrong colors when coloring logos of brands.

III. Materials and methods

The CIELAB color space was used since it is closer to human vision [30]. Color can be described in the CIELAB color system with the following triplets: L^* is called lightness, and has values between 0 and 100, while a^* and b^* are color scales. Both range between the values of -128 and 127. Red-green colors can be found on the a^* scale, while yellow-blue can be observed on b^*. This color system is shown as a three-dimensional body, with the lightness (the brightness of surface colors), chroma (representing colorfulness) axes and hue circle (or a^*, b^* axes to describe chroma and hue) where the hue is measured as a hue angle.

Participation in the tests was voluntary, and 54 people took part in them. Participants included both Hungarians and foreigners. A room that was fully dark and free of any outside light was used for the testing. The only source of illumination was the desktop display. A 60 cm distance separated each participant from the monitor. The tasks were explained before the tests began. The participants then had to fill out a form with their age, gender, nationality, and how many hours they spend each week playing virtual reality games. According to the responses, students were divided into four groups: university students from Hungary, international students, those who play video games frequently (i.e. more than 20 hours a week), and those who do not. The number of participants grouped by nationality was the following: 25 Hungarians, 8 Chinese, 7 Russians, 5 Spanish, 3 Jordanians, 2 Pakistani, 2 Tunisians, 1 Turkish, and 1 Thai students.

The participants were grouped since the sample size was too small. The groups are the following: Russians, Spanish, Hungarians, Asians (including Chinese and Thai people), and African/Middle Easterners. Then, three tests had to be completed. The results of the tests were averaged to understand the participant's memory colors. Each test had a gray background with the CIELAB color code of (67.1, 0.0, 0.0).

In the first test, called "Whole palette with an image cue", many objects that are regularly seen in daily life were depicted in white with black outlines. A color picker had to be used to color these objects. Participants are free to choose any color from the color pallet. Therefore, all possible colors could be chosen. Four images had to be colored with this method. The images that need to be colored contain small details that are not necessary for the research and can be left uncolored. The areas of each image that must be colored were specified by the researcher in the room, and that part of the image had to be colored. There were no restrictions on the colors and there was no time limit. The name of the second test was "Reduced palette with an image cue". Since the test's objective was to colorize the identical images, it is comparable to the first one. The participants were unable to mix the colors in this case though. Instead, they were limited to 12 color options and they had to select from them. Thus, predefined colors were used here. They consisted of the long-term memory colors defined in other studies. Their ΔE^*_{ab} values were also considered, and the differences should be noticeable but not excessive. Prior to the testing, ten students participated in a pre-testing session where they were only re-quired to complete the coloring task using the full palette. Each memory color was averaged as a result, and these colors were added to the other 12 colors. The name of the third test was "Reduced palette without an image cue". Because the presence of an image cue can affect memory colors, this test was also conducted. There is an image cue if the object can be seen; otherwise, the participants must rely only on their imagination. Six questions were posed to the user in this case. An answer can be selected for each question from a group of 12 colors that were mentioned in the previous test. The arrow keys could be used by the participants to navigate between the color groups. The other color group does not appear instantly after pressing the forward or back arrow keys. Only the gray background is visible for three seconds. This is important to restore the participants' ability to distinguish between the two-color groups. The three tests can be seen in Figs. 3-5.

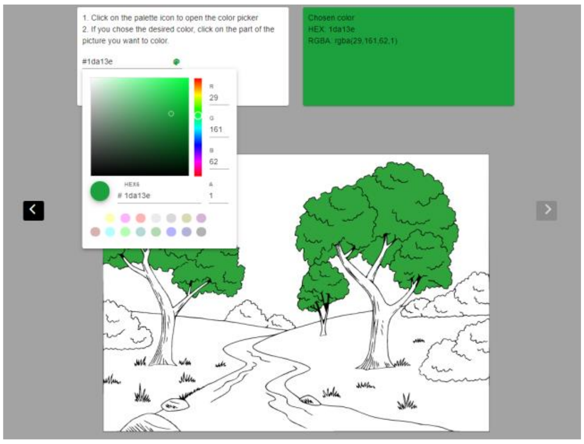

Fig. 3. Test #1: Whole palette with an image cue.

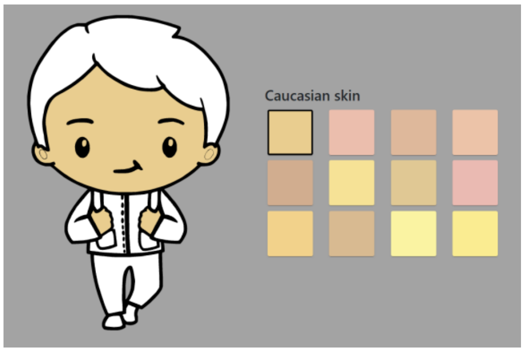

Fig. 4. Test #2: Reduced palette with an image cue.

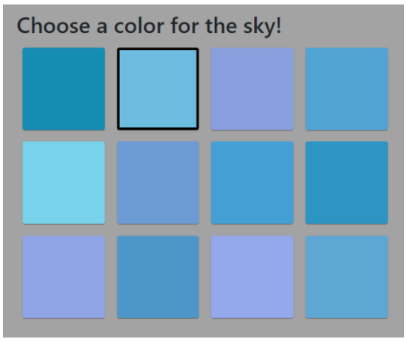

Fig. 5. Test #3: Reduced palette without an image cue.

Microsoft Excel was used to calculate the means and standard deviations. It was also used to evaluate the tests. First, for each participant and memory color examined, the mean of the three tests was determined. Additionally, these results were averaged after being divided into groups based on nationality and the duration of time spent playing virtual reality games. Then, the standard deviations for the a^* and b^* scores were determined after these groups had been formed. To understand the differences between colors, we used equation (1). The numbers in the subscript represent two different colors.

$$\Delta E^*_{ab} = \sqrt{(L^*_1 - L^*_2)^2 + (a^*_1 - a^*_2)^2 + (b^*_1 - b^*_2)^2} \qquad (1)$$

Afterward, the level of difference could be easily understood based on the values presented in Table I.

TABLE I
DISTANCES BETWEEN COLORS.

ΔE^*_{ab}	Meaning
$0 \leq \Delta E^*_{ab} \leq 0.5$	No, or barely noticeable difference
$0.5 \leq \Delta E^*_{ab} \leq 1.5$	Barely noticeable difference
$1.5 \leq \Delta E^*_{ab} \leq 3$	Noticeable difference
$3 \leq \Delta E^*_{ab} \leq 6$	Obvious difference
$6 \leq \Delta E^*_{ab}$	Large difference

Lastly, comparison was made. We compared our results between our groups. Our results were also compared to the ones of Bartleson [6], Tarczali [26], Sik-Lanyi [25], and to results received in our own preliminary survey.

IV. RESULTS

The results are divided into three subsections. In the first, they are grouped by nationality, while they are grouped by virtual reality video game playtime in the second one. The importance of an image cue is investigated in the third one. In the next subsections, the following abbreviations are used: Hu (Hungarians), As (Asians), Spanish (Sp), Russians (Ru), and African/Middle-Easterners (A/ME).

A. Results grouped by nationality

First, the memory color of skin was assessed. It can be observed in Fig. 6 that the Asian group remembered this color differently from the other ones.

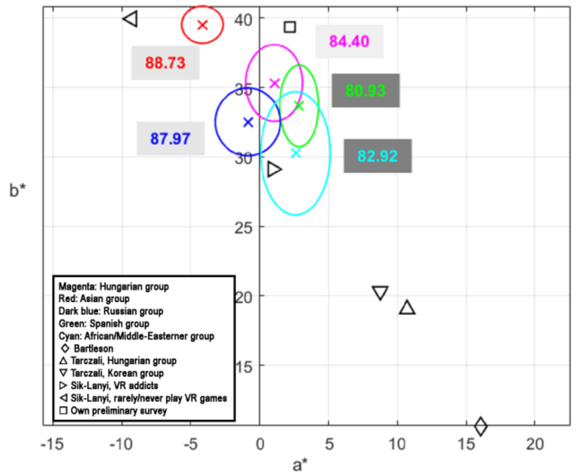

Fig. 6. Results obtained for the memory color of skin color in the CIELAB system.

The results of the remaining groups were more similar to each other, but the differences in lightness values were more noticeable. Among the four groups, Russian participants had the brightest memory color, while the Spanish group had the darkest one. These results differ the most from those that are found in Bartleson's research. The memory color of the Asian group was most similar to that of students who rarely or never play VR games in Sik-Lanyi's study. Compared to this research as well, the memory color of the Russian group was most similar to that of students who spend lots of time with computer games. Since Tarczali's research examined Far Eastern complexions in the case of Korean testers and Caucasian complexions in the case of Hungarian testers, it only makes sense to compare these results with our Hungarian group. More yellowish and fewer red results were obtained for each of these nationalities, as shown by the positive shift on the $b*$ axis and the negative shift on the $a*$ axis.

In case of the orange color, there is smaller variation between the groups as opposed to skin color. This is confirmed by the size of the ellipses as can be observed in Fig. 7. The difference between some groups, for example between the Spanish and Asian groups, was barely noticeable ($\Delta E_{ab}* < 1.5$). The largest difference was also only 5.58. Compared to skin tone, it was 13.02. There were no outlier groups for this memory color. In case of lightness value, there was only a difference of 2.86 between the lightest and darkest. The memory color of the Asian group was slightly brighter than that of the Hungarian group. Similar results were obtained in Tarczali's research, but the other group only consisted of Korean participants in it.

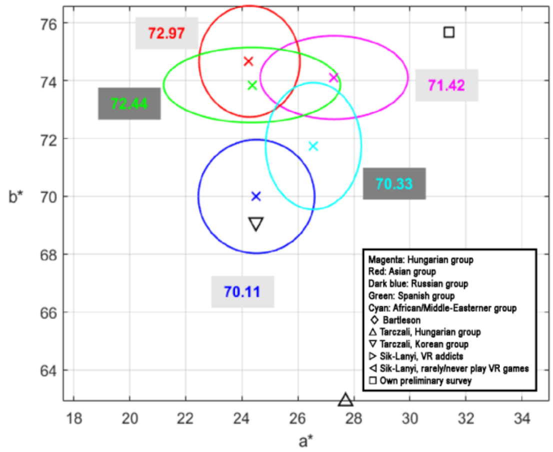

Fig. 7. Results obtained for the memory color of orange in the CIELAB system.

The next to investigate was the memory color of banana. The results are shown in Fig. 8.

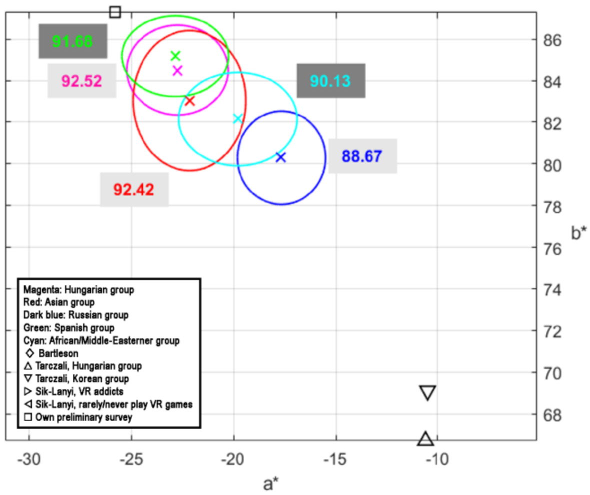

Fig. 8. Results obtained for the memory color of banana in the CIELAB system.

There was no large difference between the groups: the Hungarian group chose the brightest value, while the Russian group the darkest one. The results were not much different from the preliminary testing with 10 students, but they were clearly different from the results in Tarczali's study. In that research, it was concluded found that Korean students remembered brighter than Hungarian students. In our case however, there was no difference found between the Asian and Hungarian groups in terms of the lightness value of the banana.

Next, the memory color of the sky was investigated. The results of this examination can be observed Fig. 9.

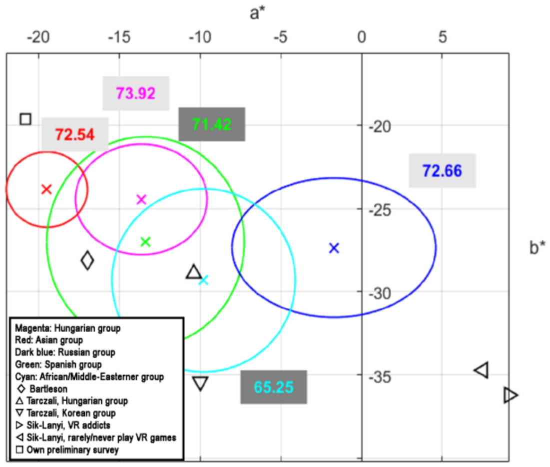

Fig. 9. The results obtained for the memory color of sky in the CIELAB system.

There were greater differences in this case, both in terms of hue and lightness. The African/Middle-Easterner group had the darkest memory color of the sky, while the Hungarian group had the lightest one. The Russian group had the most different results in terms of hue. They showed a large deviation from all groups ($\Delta E_{ab}* > 12$). In Tarczali's study, the memory colors of Korean and Hungarian skies were similarly bright, and this fact was also true in our case for the Asian and Hungarian groups.

The memory color of leaf was investigated next, and the results can be observed in Fig. 10.

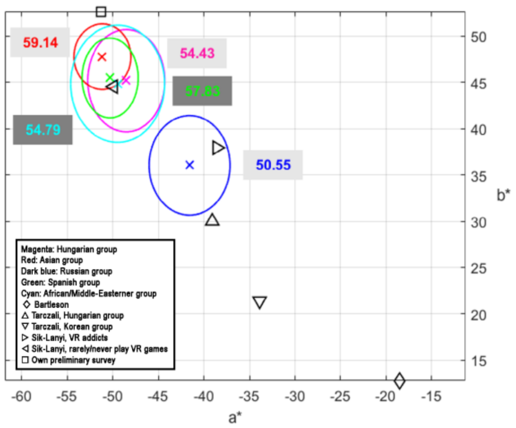

Fig. 10. The results obtained for the memory color of leaf in the CIELAB system

In this case, the memory color of the Russian group was the most different in terms of hue, and had the darkest color. The other four groups differed less from each other in hue. There was only a noticeable difference in lightness. The Asian group has the brightest memory color. Compared to the literature, four similar groups had the most similar results to those students who play VR games less often, whereas the Russian group's result was similar to the results of students who play with VR games often. Tarczali concluded in her research that the Korean leaf was less saturated compared to the Hungarian one. In our case there was no large difference between the two groups.

The memory color of grass was investigated next and the results can be observed in Fig. 11.

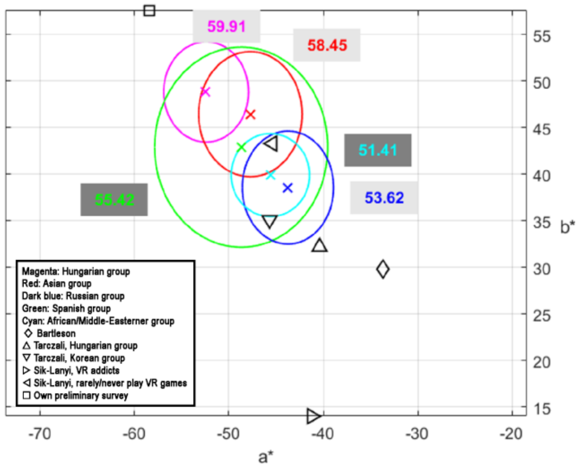

Fig. 11. Results obtained for the memory color of grass in the CIELAB system.

In contrast to the memory colors of leaf, none of the groups had outlier results. The Hungarian group produced the brightest memory color, the other ones the darkest. For leaf, the results of the Russian group were very similar to that of students who played several hours of video games in Sik-Lanyi's study, but this case was not true for the grass. The results do not differ from the Bartleson study to the same extent as for skin color or leaf. In Tarczali's research, the memory color regarding Korean grass was brighter and more saturated than that of the Hungarian grass. However, in our research, opposite results were found. The Asian group yielded a less saturated color than the Hungarian one. The results were only slightly darker.

Lastly, the memory color of river was examined. The results are shown in Fig. 12.

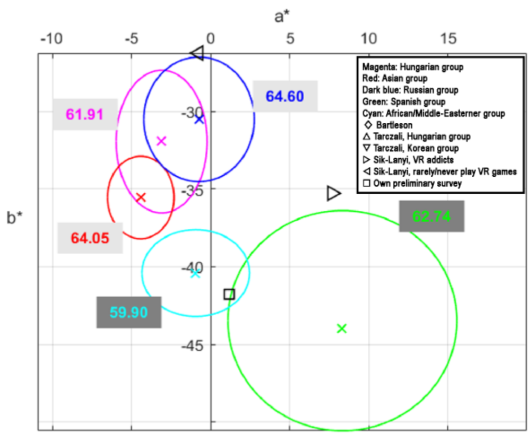

Fig. 12. The results obtained for the memory color of river in the CIELAB system.

For this memory color, the Russian group chose the brightest colors and the other ones the darkest colors. There were also a variety of results regarding hue, since none of the comparisons were below the “obvious difference” category. The colors of the Hungarian, Asian and Russian groups were closer to the memory colors of the students who rarely played VR games in Sik-Lanyi’s study. The results of Spanish and African/Middle-Easterner groups were closer to the memory colors of students who play several hours of VR games in the same research.

B. Results grouped by the amount of time spent playing virtual reality games

Next, the participants were divided into two groups based on their virtual reality game time: these groups are students who play many hours of VR games (at least 20 hours a week) or not.

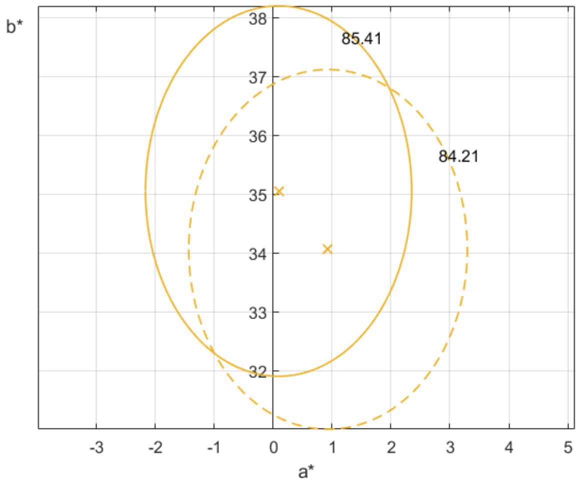

Fig. 13. Results obtained for the memory color of skin color and their dispersion ellipses. Solid line: participants who played few hours, dashed line: participants who played several hours.

Fig. 13 shows the results of students who play few hours (solid line) and of those who play several hours (dashed line) of these types of games. For the memory color of skin, the difference between the two groups was small ($\Delta E_{ab}* = 1.39$). In the study of Sik-Lanyi, there was a significant difference ($\Delta E_{ab}* = 20.17$) between the results of the same two groups.

Fig. 14 shows a comparison of the memory colors of oranges and bananas in separate coordinate systems.

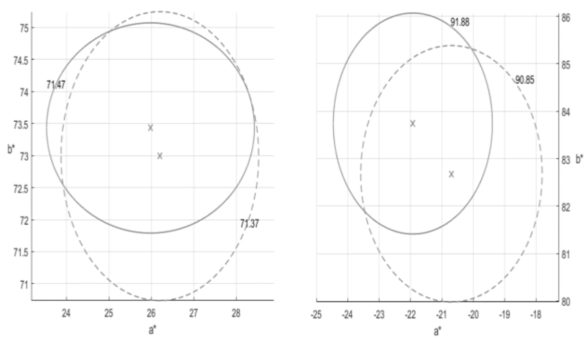

Fig. 14. Results and dispersion ellipses regarding the memory colors of oranges (left) and bananas (right). Solid line: participants who played few hours, dashed line: participants who played several hours.

In case of these two memory colors, there was no difference between participants who play several or few hours. The difference for bananas falls into the "barely noticeable" category ($\Delta E_{ab}* = 1.68$), while the difference for oranges falls into the “not, or barely noticeable” category ($\Delta E_{ab}* = 0.18$).

Fig. 15 shows the results of the memory colors of river and sky in a shared coordinate system.

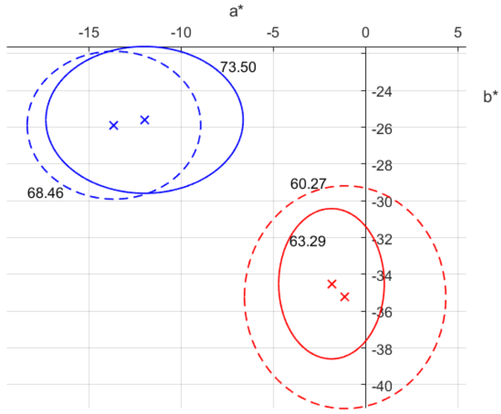

Fig. 15. Results and dispersion ellipses for the memory colors of sky (dark blue) and river (red). Solid line: participants who played few hours, dashed line: participants who played several hours.

We can already see differences in hue and lightness between students who played several or few hours. In case of both memory colors, the colors of those who played several hours were slightly darker. The difference between the two groups were in the category of “obvious difference” (sky: $\Delta E_{ab}* = 5.57$; river: $\Delta E_{ab}* = 3.11$). In Sik-Lanyi’s study, there was a similar magnitude of difference between the two groups for the sky, but the memory color of students who play several hours was not darker, whereas it was is darker in our case. In the previously referenced study, there was a large difference between the colors of river. However, it was not as large as in our case, but those who play several hours remember darker rivers, whereas in the other study it was just brighter.

Fig. 16 shows the memory color results for leaf and grass in a shared coordinate system.

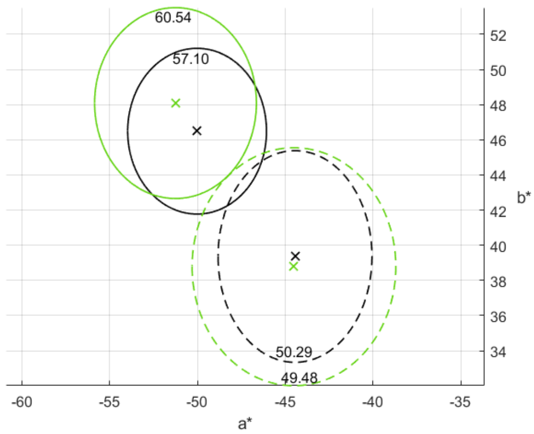

Fig. 16. Results and dispersion ellipses regarding the memory colors of leaf (black) and grass (green). Solid line: participants who played few hours, dashed line: participants who played several hours.

For these two memory colors, the difference between the two groups was most noticeable. For leaf, large differences were found ($\Delta E_{ab}* = 11.61$), while for grass the value was even greater ($\Delta E_{ab}* = 15.99$). A surprising result was that both groups chose similar colors for grass and leaf. In case of both memory colors, the darker value was obtained by the group who played several hours. These results strengthen the conclusions of Sik-Lanyi, although the two groups do not differ to the same extent. In the referenced study, the differences were even larger (leaf: $\Delta E_{ab}* = 24.03$; grass: $\Delta E_{ab}* = 54.31$).

C. *Results grouped by whether an image cue is present*

As was already described in the study, 54 people participated in the study regarding memory colors. They performed three tests for seven memory colors. In both cases, the colors for the second and third tasks were the same. However, their order was different. Out of all choices (378), 110 were the same and 268 were different. Thus, despite choosing from the same color palettes, different colors were selected in 70.90% of the decisions. This confirms the fact that the presence of the image cue influences the selection of colors.

V. Discussion

Regarding memory colors, banana and orange were those two memory colors that the students agreed on the most. Blue and green memory colors, on the other hand, led to smaller agreements between students. We can also conclude that memory colors can occasionally differ by nationality. It should be noted that not all memory colors differ, and not across all nationalities. The findings in the literature can be extended by our results, since culture can influence how colors are remembered [28]. If the results were grouped by virtual reality game playtime, a similar effect could be seen. Since not all memory colors are affected, it can only be partially verified whether virtual reality games have an impact on long-term memory colors. The memory colors of some objects were darker for people who spent more than 20 hours a week playing virtual reality games. These results build on the literature since playing video games caused grass to appear darker in people's memories [24, 25]. The choice of colors was similarly influenced by the presence of an image cue, which also supports the findings in the literature [27].

When compared to the results reported in the research of Bartleson [6], the memory colors of leaf, skin, and grass greatly differ from the findings of this study. However, this difference is presumably due to the fact that our testing was carried out on a laptop.

Naturally, this research has its own limitations as well. The tests should be conducted with additional people to receive more accurate results. Additionally, as can be seen, numerous international groups' results and that of the students from Hungary were similar. The following question might be asked given that the majority of students had spent more time in Hungary: Can a longer stay in a foreign county affect memory long-term memory colors? Further investigation is necessary in this regard.

VI. Conclusion

To investigate the cognitive effect of what we see, an application was developed during this study. It used the CIELAB color space. Three types of tests were conducted regarding memory colors.

It could be observed that the dispersion ellipses of banana and orange were the smallest. These two colors had the highest agreement between the students. The memory colors of river and grass produced the largest dispersion. Differences between memory colors of various nationalities were found, but not for all memory colors, and not between all nationalities. Playing virtual reality games also influenced memory colors, although this was also partially confirmed, since this cannot be said for all memory colors. Regarding image cues, their presence had an effect on memory colors.

The colors of the second and third tasks were the same, just mixed. In 70.90% of the decisions, a different color was chosen in the third task, despite the fact that the subjects could choose from the same set of colors. This confirms the effect of the presence or absence of an image cue on color choice.

Acknowledgment

This work has been implemented by the TKP2021-NVA-10 project with the support provided by the Ministry of Culture and Innovation of Hungary from the National Research, Development and Innovation Fund, financed under the 2021 Thematic Excellence Programme funding scheme. We would like to thank Anna Dömötör for developing as well as organizing the tests.

References

[1] Sik-Lanyi, C. Testing methods of Colour-Fidelity and Barrier-Free Design of Virtual Worlds. D. Sc. Theses, Hungarian Academy of Sciences, Budapest, Hungary, 2020

[2] Natural Color System – The International Language of Color Communication. Available online (accessed on 12.02.2023.): http://www.ncscolour.com/

[3] MacDonald, L. *Colour in Computer Graphics*; Lecture Notes, 2nd edition, MacColor Ltd, 1998.

[4] Elgendy, M. Indoor Navigation for People with Visual Impairment. PhD Thesis, University of Pannonia, Veszprem, Hungary 2021

[5] Hering, E. *Outlines of a Theory of the Light Sense*; Harvard University Press: Cambridge, MA, 1964; ISBN 9780674649002

[6] Bartleson, C. J. Memory Colors of Familiar Objects. *J. Opt. Soc. Am.* 1960, 50, 73–77, DOI: 10.1364/josa.50.000073

[7] Jin, E. W.; Shevell, S. K. Color Memory and Color Constancy. *J. Opt. Soc. Am. A Opt. Image Sci. Vis.* 1996, 13, 1981–1991, DOI: 10.1364/josaa.13.001981

[8] Siple, P.; Springer, R. M. Memory and Preference for the Colors of Objects. *Percept. Psychophys.* 1983, 34, 363–370, DOI: 10.3758/bf03203049

[9] Nilsson, T. H.; Nelson, T. M. Delayed Monochromatic Hue Matches Indicate Characteristics of Visual Memory. *J. Exp. Psychol. Hum. Percept. Perform.* 1981, 7, 141–150, DOI: 10.1037//0096-1523.7.1.141

[10] Newhall, S. M.; Burnham, R. W.; Clark, J. R. Comparison of Successive with Simultaneous Color Matching. *J. Opt. Soc. Am.* 1957, 47, 43, DOI: 10.1364/josa.47.000043

[11] Bodrogi, P. Shifts of short-term colour memory. PhD Thesis, University of Pannonia, Veszprem, Hungary, 1998.

[12] Baranyi, P.; Csapó, Á. Definition and synergies of cognitive infocommunications. *Acta Polytech. Hung.* 2012, 9, 67–83.

[13] Baranyi, P.; Csapo, A.; Sallai, G. *Cognitive Infocommunications (CogInfoCom)*; Springer International Publishing: Cham, Switzerland, 2016; ISBN 9783319359472

[14] Baranyi, P.; Csapo, A.; Varlaki, P. An Overview of Research Trends in CogInfoCom. In *Proceedings of the IEEE 18th International Conference on Intelligent Engineering Systems INES 2014*; IEEE, 2014.

[15] Sallai, G. The cradle of cognitive infocommunications. *Acta Polytech. Hung.* 2012, 9, 171–181.

[16] Macik, M. Cognitive Aspects of Spatial Orientation. *Acta Polytech. Hung.* 2018, 15, 149–167.

[17] Kovari, A.; Katona, J.; Costescu, C. Quantitative Analysis of Relationship between Visual Attention and Eye-Hand Coordination. *Acta Polytech. Hung.* 2020, 17, 77–95, DOI: 10.12700/aph.17.2.2020.2.5

[18] Katona, J. Measuring Cognition Load Using Eye-Tracking Parameters Based on Algorithm Description Tools. *Sensors (Basel)* 2022, 22, 912, DOI: 10.3390/s22030912

[19] Katona, J. Clean and Dirty Code Comprehension by Eye-Tracking Based Evaluation Using GP3 Eye Tracker. *Acta Polytech. Hung.* 2021, 18, 79– 99, DOI: 10.12700/aph.18.1.2021.1.6

[20] Sudar, A.; Csapo, A. B. Interaction Patterns of Spatial Navigation in VR Workspaces. In *Proceedings of the 2019 10th IEEE International Conference on Cognitive Infocommunications (CogInfoCom)*; IEEE, 2019, DOI: 10.1109/CogInfoCom47531.2019.9089998

[21] Torok, A. From Human-Computer Interaction to Cognitive Infocommunications: A Cognitive Science Perspective. In *Proceedings of the 2016 7th IEEE International Conference on Cognitive Infocommunications (CogInfoCom)*; IEEE, 2016, DOI: CogInfoCom.2016.7804588

[22] Wolfe, J. M.; Kluender, K. R.; Levi, D. M. Sensation & Perception; Oxford University Press, 2018

[23] Hansen, T.; Olkkonen, M.; Walter, S.; Gegenfurtner, K. R. Memory Modulates Color Appearance. *Nat. Neurosci.* 2006, 9, 1367–1368, DOI: 10.1038/nn1794

[24] Sik-Lányi, C.; Sik, A.; Sik, G. "Virtual world – „A brave new world" – but what kind of colours are used in these virtual environments?" Poster, 26TH Session of the CIE, 4 July – 11 July 2007, Beijing, China, vol. 1. D1, 99–102, 2007

[25] Sik-Lányi, C. Investigating of Memory–Colours of Intellectually Disabled Children and Virtual Game Addict Students. In *Symposium of the Austrian HCI and Usability Engineering Group*; Springer: Berlin, Heidelberg, 2009; pp. 463–475

[26] Tarczali, T.; Park, D.-S.; Bodrogi, P.; Kim, C.Y. Long-Term Memory Colors of Korean and Hungarian Observers. *Color Res. Appl.* 2006, 31, 176–183, DOI: 10.1002/col.20192

[27] Tarczali, T. Investigation of Colour Memory. PhD Thesis, University of Pannonia, Veszprem, Hungary, 2007

[28] Smet, K. A. G.; Lin, Y.; Nagy, B. V.; Németh, Z.; Duque-Chica, G. L.; Quintero, J.M.; Chen, H.-S.; Luo, R. M.; Safi, M.; Hanselaer, P. Cross-Cultural Variation of Memory Colors of Familiar Objects. *Opt. Express* 2014, 22, 32308–32328, DOI: 10.1364/OE.22.032308

[29] Sik-Lanyi, C.; Miklós, B.; Szőcs-Józsa, T. Well-Known Brands for Testing Colour Memory. In Pannonian Conference on Advances in Information Technology (PCIT 2020); 48–55, 2020

[30] Hill, B.; Roger, T.; Vorhagen, F. W. Comparative Analysis of the Quantization of Color Spaces on the Basis of the CIELAB Color-Difference Formula. *ACM Trans. Graph.* 1997, 16, 109–154, DOI: 10.1145/248210.248212

Cecilia Sik-Lanyi studied Mathematics and Computer Science. She obtained the degree dr.univ (1993) and of Ph.D. (2000) at the University of Pannonia, D.Sc. (2022) at the Hungarian Academy of Science. Currently she is a professor at the University of Pannonia. Her research area is Virtual Reality, Serious Games and Colour Science. She has published more than 500 referred articles and conference papers and worked as guest editor for many renewed journals and books. She received several awards, the most important ones are:
– "Master teacher" award of the Hungarian Ministry of Education in 2001,
– "AAATE-diamond-award" of the Association for the Advancement of Assistive Technology in Europe in 2015,
– "King Salman Award for Disability Research" of the King Salman Center for Disability Research in the Kingdom of Saudi Arabia in 2018.

Bence Halmosi is a PhD student at the Faculty of Information Technology of the University of Pannonia, Hungary. His research area include artificial intelligence, human-computer interaction and virtual reality.

Jinat Ara graduated from Southeast University, Bangladesh in 2018 with a bachelor's degree in Computer Science and Engineering (CSE). Following that she obtained her master's degree in 2020 from Jahangirnagar University, Bangladesh from the Department of Computer Science (CS). At the same time, she worked as a Software Engineer at Odyssey Apps, Dhaka, Bangladesh. Currently, she is pursuing her Ph.D. degree at the Faculty of Information Technology, University of Pannonia, Hungary. Her research area for her Ph.D. studies on the area of "accessibility investigation in web platforms or environments". Additionally, she has a keen interest in conducting cutting-edge research and currently, she is carrying around six years of research experience in several areas of computer science. Her area of research interest is 'Machine Learning (ML)', 'Virtual and Augmented Reality', 'Assistive Technologies', 'Web Technologies', 'Artificial Intelligent (AI)', 'Natural Language Processing (NLP)' and 'Automated Vehicles (AV)'.

Judit Szűcs is an Assistant Professor at the Faculty of Information Technology of the University of Pannonia, Hungary. She received her PhD degree in 2021 in Computer Science at the University of Szeged. Her main interests include binary tomography, image processing, and computer vision. She has 30 scientific publications which include 6 journal papers, and 19 studies found in various conference proceedings. She is an IEEE member since 2023.

Tibor Guzsvinecz is an Assistant Professor at the Faculty of Information Technology of the University of Pannonia, Hungary. He obtained his PhD degree in the field of Information Science in 2021. His research areas are data science, gamification, human-computer interaction, spatial ability, and virtual reality. He authored 69 scientific publications which include 19 journal papers, and 41 studies found in various conference proceedings. At the moment, he is an editor of a book project about gamification. He is an IEEE member since 2023.