Testing methods of Colour-Fidelity and Barrier-Free Design of Virtual Worlds

The theses submitted for the

Doctoral Degree of the Hungarian Academy of Sciences

(D.Sc.)

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Veszprém, 2020

’We ourselves feel that what we are doing is just a drop in the ocean.
But the ocean would be less because of that missing drop.’
Mother Teresa

Acknowledgement

I am especially grateful to † Professor János Liszi, who was the supervisor of my first doctorate degree. Thank you † Dr. József Vass, who was one of my heads of department, who encouraged me to deal with multimedia. I owe tremendous gratitude to † Professor János Schanda, from whom I was able to learn the knowledge needed for colour science research and in whose laboratory, I was able to work for almost two decades. I am grateful for the research freedom he had given to me.

I wish to thank my colleagues for their support, especially Dr. Éva Orbán-Mihálykó for her professional advice in statistical analyses.

I cannot emphasize how vital a role my B.Sc., M.Sc. students had in creating the software that were developed within the framework of their dissertation and diploma thesis. Special thanks to the work of my Ph.D. students.

I am deeply grateful to the special education teachers of the Hungarian special schools and the specialists of the rehabilitation institutes for their useful advice. I can rely on all this knowledge to this day when designing new software.

I am very grateful to the researchers and lecturers I met in the framework of the European Union projects supporting various research tasks. I would also like to thank Professor Emeritus Pier Luigi Emiliani, former Director of the Institute of Applied Physics “Nello Carrara” (IFAC), who invited me to the first FP6 project based on my publications. I would like to thank Dr. Árpád Kelemen, a professor at the University of Maryland University, for his joint medical IT research in recent years.

In addition to the University of Pannonia, the work presented in the dissertation was supported not only by the various projects detailed in Chapter 4 but also by the “King Salman Award for Disability Research” awarded to me by the King Salman Center for Disability Research. [136] I would also like to thank the moral support of the “AAATE-Diamond-Award” awarded to me by the Association for the Advancement of Assistive Technology in Europe.

I am eternally grateful to my whole family, my husband, my children, and their families for being patient and supporting me in every way possible.

Preface

Developments in computer science and information technology have opened up new avenues for more realistic visual images. As a consequence, new disciplines, such as computer graphics and virtual reality, have been born. The question of colour-fidelity display is an exciting and challenging part of this process. One vital area of related research interest focuses on user demands and consequently on legitimising the need for barrier-free designs, for instance enabling people who are colour blind to freely obtain information.

With the appearance of the Internet the speed information has greatly increased, social networks and online gaming communities have appeared. This dimension encompasses millions of users. Social networks as well as online games can be understood as virtual worlds.

Among the priorities of the European Commission we can find the simplification of modern digital contract rules and the promotion of access to digital content. Another fact is that by 2020, 25% of the EU's population will be over 65 years, therefore, new solutions are needed for the daily care and health monitoring of the elderly, who may not be able to move out of their homes, e.g. digital services for healthcare and social care at distance. Barrier-free Internet and software is an essential part of this process.

I have been engaged in two main research areas of human-computer interaction. I have made several measurements in both research areas. The first area focuses on the topic of colour-fidelity display concerning computer software, the second focuses on designing barrier-free applications. The two areas are closely related as at least 10% of users tend to show a certain degree of impairment, a large proportion of it being of visual nature. This observation necessitates the present Theses to have two different areas:

- one is the colour-fidelity of virtual reality-based games and designing colour correct web pages,
- the other is the area of software ergonomics, especially barrier-free design so that anyone can easily use software or web pages. These can be either games, educational materials, or health, medical IT rehabilitation applications.

In the field of colour design discussed in the first part of my research I measure the typical colours of the most popular virtual reality-based games for the purpose of colour correct design of similar games. The second step of this research is to investigate how the colours of games influence the users' memory colour. The third part of colour science research is to check the colour of each Hungarian university website, determining whether people with colour deficiency can use them. Based on the results, I shall propose a method for the colour-correct design of virtual reality-based games and websites, so that people with colour deficiencies will not lose information, and are able to use them in an accessible way.

In the field of Universal Design and Health Informatics I have conducted multiple research activities on barrier-free design of both multimedia and VR games and accessible WEB. I created the design requirements and testing methods of customisability concerning non-leisure multimedia and VR games for skills development and rehabilitation use. I have done two kinds of research on accessibility testing of "Web accessibility investigations": by determining the most typical mistakes of websites both by automatic validators and experts' questionnaires and recommendations to design and testing methodology. Based on my recommendations, I have proved that it is possible to create a barrier-free website, which is useful for patients and improves nursing workflow, efficiency, and patient education.

In the listed results my contribution was significant; however, some of the results have been achieved partially with co-authors.

Since I obtained my Ph.D. the Theses have been completed by new research and new findings. Apart from few publications on the results of our collaborative work with Professor János Schanda, most of the publications feature my collaboration and work as supervisor in connection with B.Sc. and M.Sc. students and in one case a PhD candidate. All contributors and co-authors are indicated in the present research.

Contents

Chapter 1

Introduction

1.1 Subject of the theses, main objectives, motivation

The improvement of computer science, information technology, and the available computing capacity opened the doors for more realistic visual images. As a consequence of this development, new disciplines were born, e.g. computer graphics, and virtual reality. The question of colour-fidelity display is an interesting part of this process. At the same time, these new research fields must pay attention to the demands of users as well. Some of them, however, have such expectations which, if the principles of 'Design for All' and demographic changes are taken into consideration, legitimise the need for barrier-free designs. Thus, enabling people who are colour-blind to freely obtain information is also involved in this.

With the appearance of the Internet the speed information has greatly increased, social networks and online gaming communities have appeared. This dimension encompasses millions of users. Social networks as well as online games can be understood as virtual worlds.

I have been engaged in two main research areas during the last two decades. The first area focuses on the topic of colour-fidelity display concerning computer software, the second on designing barrier-free applications. The two areas are closely related as minimum 10% of users tend to show a certain degree of impairment, a large propotion of it being visual in nature. [71] This observation necessitates the present Theses to have two different areas:

- one of them is the colour-fidelity of virtual reality-based games and designing colour correct web pages,
- the other one is the area of software ergonomics, especially barrier-free design so that anyone can easily use the particular software, web page. These can be either games or educational materials or health, medical IT rehabilitation applications.

Virtual Environment (VE): a synthetic, spatial (usually 3D) world seen from a first-person's perspective with real-time control of the user. In some literature, Virtual Reality (VR) and Virtual World are more or less synonymous with Virtual Environment (VE). [72] More specifically, VEs are distinguished from other simulator systems by their capacity to portray three-dimensional (3D) spatial information in a variety of modalities. They are able to exploit the user's natural input behaviours for human-computer interaction, and their potential to "immerse" the user in the virtual world. [68] The effects of human differences in immersive VR environments is a cutting edge research topic. [69] Inside this area, the colouristic features of small and large surfaces can be a new research topic validated by many real-life experiments and researches. [73,74]

More and more online three-dimensional (3D) games are to be found these days. According to Steinkuehler, the current global player populations of the most popular three games that she has studied over the past few years totals over 9.5 million – a population which rivals, e.g. most US metropolises. [75] However, there is an ever expanding gap between game heroes and the characteristics of real-life people. This difference is reflected in the choice of colours as well. Kids and youngsters are playing more and more VR games.

It was proven as an interesting hypothesis, whether the colorization of VR games has any influence on the users' memory colours. For this reason, I was aimed at studying the colourisation of different VR games, then I compared and contrasted the results with memory colours found in the scientific literature. [76,77]

The study of cultural differences has become an emerging field of research over the past decade. Cultural differences have an impact on human interaction with information. [78-80] In the last 1.5 decades I have been conducting researches on cultural differences concerning colour theory. It is widely known that colours may influence human emotions and feelings in the sense that some colours may make one happy, while some colours may evoke depression. [81]

Cross-culture studies indicate that different cultural groups show different responses and preferences to colours [82], and colour combinations [81,83]. Sato el al. [84] conducted surveys based on three characteristics: the influence of colours, chroma, and the relation of warm-cool colours. Smet et al. [85] carried out colour memory tests in different continents. It is clear to see from these few researches that colour test are often psychophysical experiments as well.

Multimedia applications often use graphical drawings instead of photographs because they can be more efficiently moved and stored. In many cases users regard pictures with fewer colours appropriate for use. In case of virtual reality (VR) simulations (most importantly those for purposes of therapy), a more realistic visualisation is required. Graphic designers – 3D modellers – have to choose from a great amount of hues representing qualities. Most multimedia programs enable a wide range of colours from their own palette but they do not provide adequate instructions as to how and where these colours are worth applying. Formerly, it was the task of graphical designers to colour pictures. Nowadays this task is being passed onto IT engineers – more frequently called animators – programming animations. Pictures have an aesthetic value as well, which means that the chosen colours cannot clash and that they have to be in harmony. There are several guiding principles regarding colour harmony. [86] When it comes to virtual museums, one could expect that paintings and other pieces on display are shown realistically.

Among the previous scientific researches, I must mention our multimedia-enhanced teaching resources as well. [1] One of the key areas of colour research is how users with some colour vision deficiency see software user interfaces and web pages. As populations expand so does the number of people with colour vision deficiency. [87,88] This is not negligible as it means hundreds of millions of people. Therefore, when designing software we must make sure that the colours used are harmonious and that the used colours are visible for a user with colour vision deficiency. In other words, they should be able to use the given software or website without problems.

The research in the field of barrier-free design has boosted recently. There is a growing number of publications and several important applications. Due to length restrictions, these will not be listed here [89,90] (apart from a collection of my publications) [2,3,30-33,55], and I would rather support the actuality and importance of barrier-free design based on data.

Most software engineering companies have not been developing products for users with special needs because they do not see a potential market in these users. However, figures have proven that at least 10% of the world's population features some kind of impairment.[71] This number is estimated to reach 14% in the USA, and 65% of the population older than 65 years is to become handicapped. Disabilities correlate with age. In developed societies more and more people turning older than 75 are likely to have some kind of impairment. This group will comprise 14.4% of the population by 2040, compared with 7.5% in 2003 – it is almost a twofold increase. [104]

Another fact is that by 2020 25% of the EU's population will be over 65 years. Money spent on pensions, health and long-term care is expected to increase by 4-8% of the GDP in the forthcoming decades. These expenditures will triple by 2050. Let us not forget that the combined wealth of older Europeans is more than €3000 billion. [105] So if a company does not respond to launching barrier-free products, it is going to lose a great deal of potential customers/users.

New solutions are needed for the daily care and health monitoring of the elderly, who may not be able to move out of their homes [106], e.g. digital services for healthcare and social care at distance. [107]

Barrier-free Internet and software is an essential part of this process. It is not an easy task to make the Internet, software and VR applications barrier-free. The existence of the principles and standards of universal design/Design-for-All is not everything. [89,90] The regulations for a barrier-free Internet also seem inadequate. [108,109] The question is more complex if users' special needs are also being taken into account. The reason why I have done much research is to compile a list of minimum requirements that should be considered by all software engineers and computer specialists for developing the newest software and websites. [2,3,30-33,55]

Among the priorities of the European Commission we can find the simplification of modern digital contract rules, the promotion of access to digital content, and the enhancement online sales. [91,92] They wish to support digital market strategies in the member countries. Moreover, they are introducing new e-commercial regulations in order to make buying and selling goods inside the EU easier. [93] In Hungary people made an online purchase more than 22 million times in 2015. [94] The retail turnover rate in Hungary grew by 18% in the first half of 2016, compared with the data from the previous year, and it reached 131 billion forints. [95] This number continues to grow. According to a survey of online sales with about 3,200 Hungarian web shops, domestic online retail reached a net annual turnover of HUF 425 billion in 2018, which is about 17% higher than the level in 2017 and 4.5% higher than the total Hungarian retail turnover. [96] According to the sector-level survey conducted for the seventh year, domestic online retail reached a gross annual turnover of HUF 625 billion in 2019, which was about 16% higher than the level in 2018. Online sales account for 6.3% of the total Hungarian retail turnover. [97]

Additionally, more than half of online shoppers have already purchased from a foreign web store. [98] Hungarian consumers spent about 145 billion HUF gross in foreign webstores in 2019. [99] More than 50,000 new novice online shoppers appeared in a month and a half at the start of the epidemic. [100]

We are not just looking at online commerce, but a much wider area of internet use. If we look at recent events, I mean, the pandemic caused by the COVID-19 virus, which made it necessary to stay home. Deeply concerned both by the alarming levels of spread and severity, and by the alarming levels of inaction, WHO made the assessment that COVID-19 can be characterized as a pandemic on 11st March 2020. (WHO). [101] As the Covid-19 pandemic outbreak made working from home the norm for millions of workers in the EU and worldwide, a new analysis of the European Commissions' Joint Research Center (JRC) explores the challenges that countries, employers and workers are facing in adapting to the new work-from-home environment. [102,103]

Millions and millions of people have been forced to work from home and learn from home, not to mention telemedicine. This situation and the need for home offices also support the importance of making the Internet accessible.

Economic analysts of Virtual Reality & Augmented Reality (VR/AR) estimate a growth by $182 billion in the next 10 years. It is made up of $110 billion from hardware and $72 billion from software. Global augmented reality (AR) and virtual reality (VR) market is estimated to generate a revenue of USD 22.1 billion in 2020 and is expected to reach USD 161.1 billion by 2025, witnessing 48.8% Compound Annual Growth Rate (CAGR) during the forecast period. The market is driven by the factors such as increasing responsiveness about this technology, rapid acceptance of AR and VR technology among various industry domains and the amalgamation of AR and VR to develop the mixed reality that can be implemented for prospective applications. [110] Economic analysts of Virtual Reality and Augmented Reality (VR/AR) estimate a growth by USD 182 billion in the next 10 years. It is made up of USD 110 billion from hardware and USD 72 billion from software. [111] The leading software companies, e.g. Microsoft, are more reactive to developing barrier-free software thus there is a growing need for barrier-free design in the game industry as well.

3.7 million people reported playing some sort of video game in 2017, which constitutes 58% of the Hungarian population between 18 and 65 years of age. The turnover of the sector in 2017– including video game, hardware and in-game purchases – exceeded 28 billion Hungarian Forints. There is a steady income of reinforcements, too: more than half of all children play some kind of video game, according to eNET's latest research on gaming in 2018 (Fig. 1.1). [137]

The large number of this research raises additional questions in the field of colour design and accessibility.

Figure 1.1. Research about Hungarian videogames player in 2017, adapted from [137]

Believing that only young people play videogames would be a great misconception: in 2018, people aged 65+ outnumbered children under five years old globally for the first time in history. [138] By 2050 over 16% of the world's population will be 65 years or older. [139] According to Nielsen and even as far back as 2012, reports showed us that over 70% of US disposable income is controlled by individuals aged 65 and above. [140] This consumer age-group is not a stranger to games. "Peak NES (Nintendo Entertainment System) sales" happened when they were in their 30s and 40s, with many of their children engrossed in the first generation of Mario and Zleda games. Furthermore, this age group is currently one of the most engaged mobile game player segments in the world as it is illustrated on Figure 1.2.

The largest group of mobile gamers is 55+ (albeit this is also the largest age bracket within the data). [141]

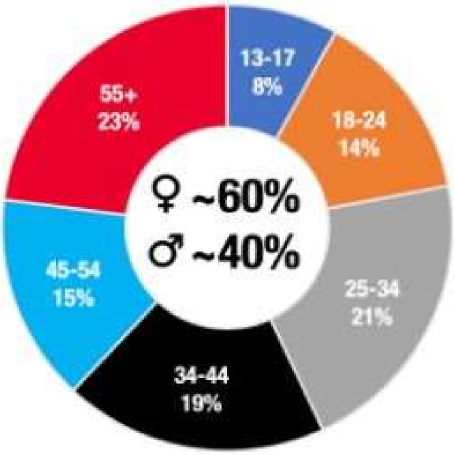


Figure 1.2. Mobile game player segments in the world, adapted from [141]

Colour blindness correlates with age; 45% of people in their mid-70s, and up to 50% of those aged 85 or older, are reportedly colour blind. [141]

To sum it up, from the demographic figures, the demands of users, digital game industry, and the e-commercial and e-health endeavours, we can see how inevitable are the barrier-free software and Internet accessibility. In addition to all this comes the importance of colour fidelity as well. [5-8]

The aim of the present Theses is to put forward solutions to the highlighted barriers and issues based on measurements and statistical analyses and to find answers to the users' demands in order to provide them a higher standard of living. It offers testing methods, user-friendly solutions for colour-fidelity and accessible Internet and software designs.

1.2 Structure of the thesis

The outline of the dissertation is as follows. In my thesis I investigated two different parts of my research, therefore I structured it as the following. Following this short introduction Chapter 2 presents the fundamentals of my research, both in colour science and accessibility research. I also provide the definition of Virtual Reality (VR), Serious Games (SG), Human-Computer Interaction (HCI) and Universal Design. This chapter also includes the methodological contributions of the thesis.

The scientific contributions of the Author are presented in Chapters 3-5. The researches of the new scientific results are written in the following three chapters as the main three thesis groups. Each of these chapters correspond to a Thesis Group listed in the Conclusion (Chapter 6), by giving the background of the selected problems and the main steps of the solution, particularly focusing on the validation of the new scientific results which is performed in experimental ways in most cases.

Chapter 3 “Colour design and games” deals with the measurement of colours of the most popular virtual reality games in different categories and the influence of memory colours.

Chapter 4 discusses “Web accessibility investigations” by measuring the most typical mistakes of websites both by automatic validators and experts’ questionnaire and recommendations to design and testing methodology.

In Chapter 5 “Health informatics and universal design”, I provide a complex recommendation list and testing method and prove that accessible websites can be created.

These chapters are structured in a similar way. In their first section a literature review is conducted. Afterward, the research questions and hypotheses are presented in their second section. Then the results and discussion are presented. In these three discussion subsections the hypotheses that are formed in subsections 2.2 and 3.2 and 4.2 are accepted or rejected. Based on the accepted or rejected hypotheses my theses are formed. Each research chapter is finished with a conclusion of the chapter. The fifth sub-chapter focuses on my theses.

A short conclusion and a summary of the new scientific results are given in Appendix A, whereas Appendix B is the conclusion of the thesis in Hungarian.

Appendix C is the detailed list of the publications where the author’s contribution of the Theses is clearly indicated.

Chapter 2

Fundamentals

This thesis deals with selected problems of colour fidelity and accessibility. Therefore, definitions of terms are given which are used in the thesis. It is followed by the fundamental of colour science and accessibility standards, guidelines, and descriptions of the frequently used automatic testing tools.

2.1 Definitions

2.1.1 Virtual Reality, Virtual Environment

Defining Virtual Reality (VR) can prove to be a difficult task because there is no standard definition for it. It is said to be an oxymoron, as reality that does not exist. When we speak of "Virtual Reality" (VR) we refer to a computer simulation that creates an image of a world that appears to our senses in much the same way we perceive the real world, or "physical" reality. VR is a medium, a means by which humans can share ideas and experiences. We use the word experience to convey an entire virtual reality participation session. The part of the experience that is "the world" witnessed by the participant and with which they interact is referred to as the virtual world. [142] Many other names are being used interchangeably with VR; these include Virtual Environment, Artificial Reality, Virtual Worlds, Artificial Worlds, and Cyberspace.

What is Agmented Reality (AR) and Mixed or Merged Reality (MR)? The difference and specialties are demonstrated in Figure 2.1.

A virtual world is a subset of Virtual Environment (VE). VE is one of the mostly commonly used alternative terms for platforms otherwise known as virtual worlds. The similarity in terms draws on our existing conceptual frameworks of what it means for something to be virtual, meaning that VE has been a useful bridging term. However, they are distinct, and I argue that a virtual world is a subset of VE. There are many different types of VEs which users can explore such as simulations and whilst these environments might be world-like, they are not inhabited as previously described. Failing to clarify this relationship in the past has contributed to the over extension of the term virtual world, treating it as synonymous to virtual environment. [143] A VE is a component of a virtual world. Every world contains an environment for its inhabitants. In a virtual world, this is described as the VE.

At the highest level, the taxonomy is presented in an abstract hierarchical structure represented by the four shaded boxes and their connections shown in Figure 2.2. This diagram depicts high-level relationships among the taxonomy's four major areas of usability issues. The diagram also contains another level of refinement for each of these major areas, shown as white boxes in Figure 1. For example, “VE User Interface Presentation Components” is refined into “Visual Feedback”, “Haptic Presentation”, “Aural Feedback”, and “Environmental Feedback and Other Presentations”. For every box within the diagram there is a corresponding table, which, in turn, presents specific usability suggestions and considerations. Arrows in the diagram represent “information” flow between user and VE. [144]

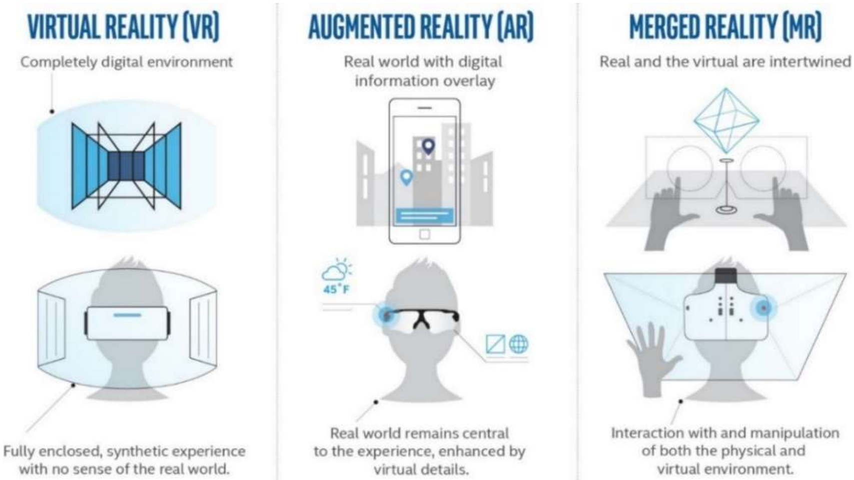


Figure 2.1. The conception of VR, AR, and MR adapted from [145]

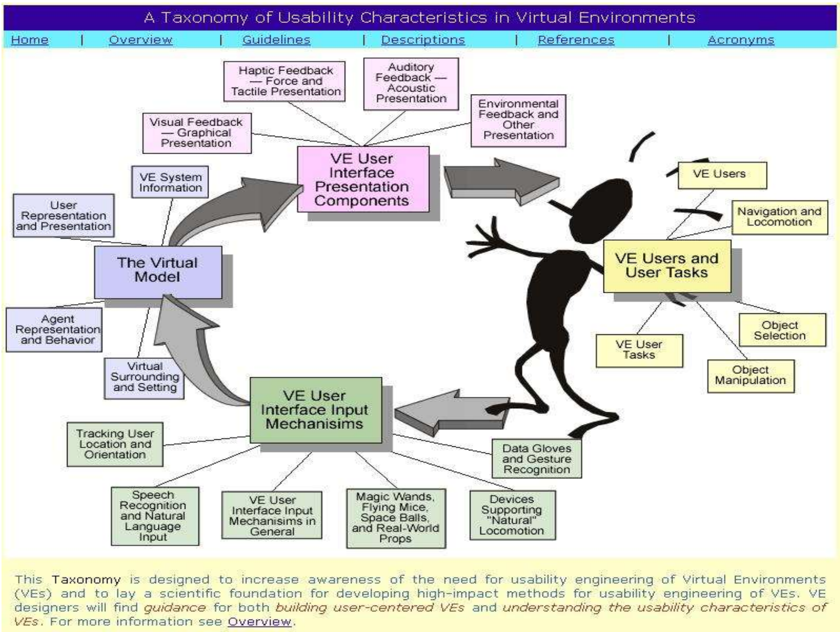


Figure 2.2. An Overview of taxonomy areas

Developing a virtual environment seems to be very difficult, complex work. Colour is part of the graphical presentation, computer graphics, virtual surrounding and setting. Barrier free or accessible design is in close connection with the users’ ability and the VE interface input mechanism. Moreover, we have to keep in mind the physical limitations that players of an older age can and do face. Therefore, I dealt with the colour fidelity and barrier free design in my thesis.

2.1.2 Human-Computer Interaction

Human-Computer Interaction (HCI) is a multidisciplinary field of study focusing on the design of computer technology and, in particular, the interaction between humans (the users) and computers. While initially concerned with computers, HCI has since expanded to cover almost all forms of information technology design. [146]

Interaction with human beings is increasingly recognized and promoted as an important aspect of software systems and products. More and more professionals in the computing industry e.g., Hefley [147], Kapor [148] call for integrating human-computer interaction (HCI) engineering with software engineering.

According to Buie and Vallone's thesis [149], the fields of HCI and software must interact and collaborate under a larger perspective that encompasses both. Each must develop a larger vision. The diagram in the Figure 2.3 indicates that HCI engineering and software engineering are separate but interact very closely. Not only do they exchange information, but each review and validates the other's products to ensure both usability and feasibility.

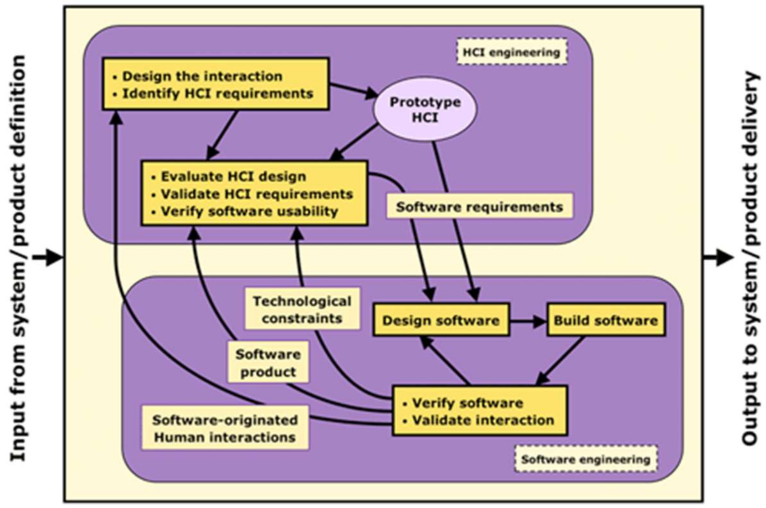


Figure 2.3. System engineering coordinates the activities of HCI engineering and software engineering.

2.1.3 Serious Games

Serious Games (SG) are electronic games whose main purpose is "serious" and not to simply entertain. The primary "serious" purposes can be to teach or train in areas such as education, semiformal educational settings, health care, advertising, politics, etc. [150] Digital games, simulations, virtual environments and mixed reality/media that provide opportunities to educate or train through responsive narrative/story, gameplay or encounters. [151] SG is built with pedagogical principles and education and training purposes, supported by gaming techniques and entertainment. [152] A classification referring to games that are specifically designed for a particular purpose. These games are often for education, training, and advertising, and are more often used in particular industries like health care and the military. [153]

Initially, serious games were considered to be games with a purpose. The basic idea behind serious games is to hide important and time-consuming tasks behind a gaming veil. They are games that have scope beyond recreation. [154]

The idea of using games or game technologies for “serious”, e.g., educational purposes is as old as the idea of “learning games” but is not limited to those forms. As opposed to games designed for entertainment, serious games can be defined as computer games aiming towards an underlying second “off-game” goal that differs from in-game goals such as finishing a level or gaining high scores. Beyond the surface of gaming actions—or embedded into those—, serious games try to evoke learning processes or even complex experiences (e.g., through taking the perspective of political refugees, trying to bring them out of a danger zone). Computer game art can be seen as a related form of serious games, aiming, for example, towards open aesthetical experiences rather than following didactic concepts and defined learning goals. [155]

2.2 Colorimetric fundamentals

2.2.1 Colour

The electromagnetic radiation reaching our eye and producing there a sensation is called colour stimulus. The sensation produces the colour perception in our brain. In scientific literature three components of colour perception are distinguished: brightness, hue and colourfulness:

- 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 never bluish; a green hue can be yellowish or bluish, but never reddish, and so on (see: Figure 2.4). [156] One can 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 are used:
  - Yellow – red: orange
  - Green – yellow: lemon
  - Blue – green: cyan or turquoise
  - 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 colour. If no hue can be determined for a colour then it is gray (or white or black). Thus, with increasing colourfulness one can speak about a gray, grayish, moderately vivid, vivid and very vivid colour perception.

The communication of the colour perception can thus be made in the following form: The complexion of the person who stands in front of me is medium bright, moderately vivid and reddish yellow. [157]

The colour stimulus can be described in a definite way using a colour order system. The colour solid contains all the realizable surface colours. There are several colour systems in use, some of them are the RGB, CMYK, CIELAB, NCS. We performed our measurements using the CIELAB system [112], because this is – contrary for example to the RGB or CMYK systems a non-device dependent system [113], it is the system now recommended by international standards. [158] It can be used not only for surface colours, but also for defining colours produced on computer monitor screens. Figure 2.5 shows this colour system as a three-dimensional body, with the lightness (the brightness of surface colours), chroma (representing colourfulness) axes and hue circle (or a^*, b^* axes to describe chroma and hue) where the hue is measured as a hue angle. In the CIELAB colour system one can describe the colour with the L^* lightness and the a^*, and b^* co-ordinates (in Figure 2.5 we show the a^*, b^* sections as two-dimensional planes). The a^*, b^* co-ordinates describe the amount of redness – greenness, and yellowness – blueness.

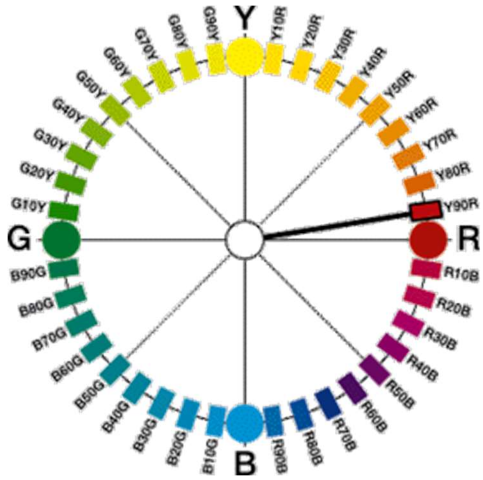


Figure 2.4. Opponent colours and colour notation in the NCS colour system [156].

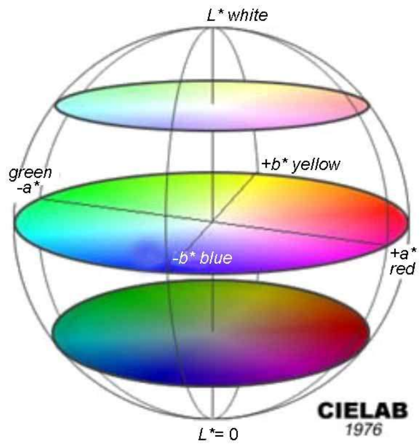


Figure 2.5. Three-dimensional graph of the real surface colours, in the system of lightness, chroma and hue.

Visually the difference between two colours is described by saying: large, medium and small. In the CIELAB system, the colour difference can either be described as the Euclidian distance between the two points representing the colours in the three-dimensional space, or can be described by the lightness difference (ΔL^*), hue angle difference (Δh_{ab}), chroma difference (ΔC^*_{ab}) where

$$h_{ab} = \arctan(b^*/a^*), \tag{2.1}$$

and

$$\Delta C^*_{ab} \text{ chroma diffrence } (C^*_{ab} = (a^{*2} + b^{*2})^{1/2}) \tag{2.2}$$

and

In case of the $L^*a^*b^*$space, the difference between two colours is calculated by the formula:

$$\ldots\Delta E^*_{ab}=((L_2^*-L_1^*)^2+(a_2^*-a_1^*)^2+(b_2^*-b_1^*)^2)^{1/2} \tag{2.3}$$

The interest and demand for the calculation of colour difference increased with the introduction of a standard observer to colorimetry in 1931 by the CIE, because it allowed for accurate determination of the tolerance of prints, colours, materials, inks, images, and multimedia equipment calibration. CIE has defined a colorimetric Standard observer, to allow for describing the colour via numbers. It represents the average person with normal colour perception. The CIE has defined two standard observers with different observation angles: 2° and 10° (1931 resp. 1964). An observer with the angle of 2° corresponds to the observation of an object with a small size (using an optical instrument), while an observer with the angle of 10° corresponds to the observation of an object in normal conditions.

As is well known, it is generally accepted that for images a ΔE^*_{ab} value between 2 and 3 is just perceptible; thus, we accepted colour differences of $\Delta E^*_{ab} \approx 2, ..., 3$ as indicative of a good reproduction. [7]

A standard observer sees the difference in colour as follows, [159,160] when:
$0 < \Delta E < 0.5$ - observer does not notice the difference, no or hardly noticeable the difference,
$0.5 < \Delta E < 1.5$ - only experienced observer can notice the difference, barely noticeable difference,
$1.5 < \Delta E < 3.0$ - unexperienced observer also notices the difference, noticeable difference,
$3.0 < \Delta E < 6.0$ - clear difference in colour is noticed, clearly visible difference,
$6.0 < \Delta E < 12.0$- observer notices two different colours, large difference.

2.2.2 Memory colours of well-known objects

The term memory colour is used for the colour of well-known, often seen objects, as in our brain we attach a colour to the given object. Memory colours are well stabilized products of our memory. They are colours we will pick from a high number of colour chips if one is asked to show the colour chip resembling the colour of human complexion, or sky blue, etc. Table 1 shows the L^**, and* h_{ab}^* values of some memory colours [35].

Table 2.1. Memory colours for well-known objects according to different authors

Memory colour	L^*	h_{ab}^*	Reference
Caucasian skin	79.5	32.9	[114]
blue sky	54.0	238.8	[114]
green grass	50.0	138.5	[115]
Asian skin	63.9	49.0	[161]
deciduous foliage	33.6	145.3	[114]

2.2.3 Colour harmony

The harmony of colours and proportions play an essential role in the appearance. Although many authors tend to neglect these issues, numerous scientific research studies are concerned with this field. All this is based on the colour perception of the eye, which, however unconsciously, may have an influence on users' decisions [15].

Scientists and artists over the last centuries [162-165] and nowadays [166] developed colour order systems where they defined rules to establish harmonic sets of colours. These colour harmony studies were based on the orderly arrangement of colours in the colour order system. The second group of authors [165,167] defined colour harmony as an interrelationship of colours. The main principles of these studies are "complementary" and "analogous" but these concepts are not consistent among the studies. Also, the colour wheel was often adopted as a tool to define these basic relationships. Judd and Wyszecki [168] define colour harmony as a more universal concept: "when two or more colours seen in neighbouring areas produce a pleasing effect, they are said to produce colour harmony". In addition, there is no consistency among the principles and the keywords of colour harmony: it is completeness according to Goethe [165], order according to Nemcsics [166] and Chevreul [167] and balance according to Munsell [163]. Many other effects (i.e. age, cultural background) of colour harmony feeling have yet to be investigated.

The harmony of hues is also represented in many art and design textbooks with reference to hue circles. Figure 2.6 illustrates four ubiquitous schemes [86].

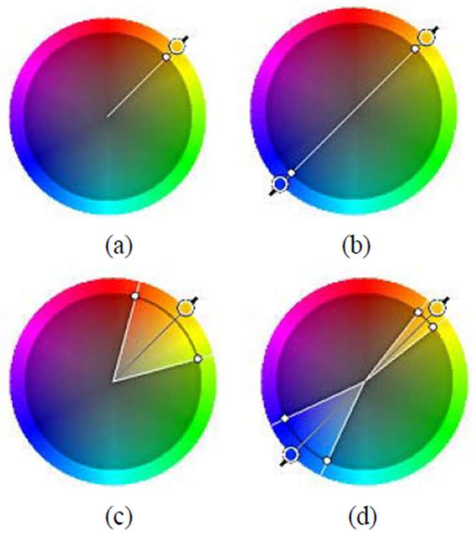


Figure 2.6. Four typical geometric relationships: monochromatic (a), complementary (b), analogous (c), split complementary (d).

- monochromatic colour harmony (where colours are chosen with the same or nearly the same hue) "Figure 2.6 a";
- complementary colour harmony (this is always represented as referring to opposite colours on a hue circle) "Figure 2.6 b";
- analogous harmony (where colours are chosen with similar hues) "Figure 2.6 c";
- split-complementary harmony (where there are basically three colours, with two being either side of the complement of the third in the hue circle) "Figure 2.6 d".

In visual experiences, harmony is something that is pleasing to the eye. It engages the viewer, and it creates an inner sense of order, a balance in the visual experience. When something is not harmonious, it is chaotic. At one extreme is a visual experience that is so bland that the viewer is not engaged. The human brain will reject under-stimulating information. The human brain rejects what it cannot organize, what it cannot understand. The visual task requires that we present a logical structure. Colour harmony delivers visual interest and a sense of order. Extreme unity leads to under-stimulation, extreme complexity leads to over-stimulation. Harmony is a dynamic equilibrium [57,58].

2.3 Web accessibility standards and validation tools

Providing a barrier-free Internet, software and VR applications is a challenging task. Already existing principles and standards of universal design/Design-for-All cannot guarantee accessibility, per se [89], and the fact that providers overlook these regulations further delays the introduction of a barrier-free Internet [169]. In 1999, the World Wide Web Consortium published the Web Content Accessibility Guidelines WCAG 1.0 [108]. Web Content Accessibility Guidelines, WCAG 2.0, was released in 2008 [109]. To complete WCAG 2.0, the researchers recorded the number of known problems identified for A, AA and AAA level guidelines. While WCAG 1.0 contains 14 guidelines with 62 checkpoints at 3 priority levels, the WCAG 2.0 has only 4 principles with 12 guidelines. Both have 3 levels of conformance: A, AA, AAA. Both provide technical advice.

The main principles and structure of WCAG 2.0:

- Principles – Top 4 principles.
- Guidelines – 12 guidelines provide the basic goals.
- Success criteria – For each guideline testable success criteria are provided. Three levels of conformance are defined: A (lowest), AA, and AAA (highest).

Several other guidelines based on WCAG 2.0 exist. For example, the standard in Canada is the Standard on Web Accessibility, [170] which follows the WCAG 2.0 guidelines. The Web Content Accessibility Guidelines for Japan, called JIS (Japanese Industrial Standards), was released in 2004 [171]. Recognizing the growing demand for an accessible internet, more and more countries pass legislation concerning accessible digital information. Countries frequently support and adopt WCAG 2.0 by referring to the guidelines in their legislation [172-175]. The USA, furthermore, specifies that all Federal electronic media must be made accessible to people with disabilities. WCAG2.0 AA standard has been approved as an appropriate standard for accessibility by the U.S. Department of Justice in multiple settlement agreements [176,177]. The European Parliament approved a draft in February 2014 which states that all websites in the public sector have to be developed to be accessible for everyone [178]. This European standard, called EN 301 549 V1.1.2, describes relevant accessibility requirements. The problem of accessibility is twofold at this juncture. Firstly, not all member states have harmonized their accessibility laws with that of the European Union, even though it was expected to take place by September 2018. Secondly, not all public sector websites had been able to comply with guidelines by September 2018. The next goal is that mobile apps in the public sector should comply by June 2021 [178,179]. Although the newest version of WCAG, the WCAG 2.1 [180,181], was released on 5 June 2018, there is no suitable, efficient automatic test tool based on these guidelines.

There are several automatic testing tools available on the World Wide Web Consortium webpage (w3.org). As people do not like to give their personal details and download any software to their computers, unfortunately most of them are not free, or the user has to log in order to use the testing tool, or user has to download it. Some others are not in English. As a result, the number of relatively good-performing test software which can be used freely in the cloud is rather limited. Based on my several years of experience, AChecker [121] and Nibbler [126] automatic testing tools are still reliable and free, and do not require installation or logging in.

AChecker [121] and Nibbler [126] are automatic testing tools. AChecker is a free tool that checks single HTML pages for conformance with accessibility standards to ensure that the content can be accessed without limitations [121]. AChecker diagnoses known problems, likely problems and potential problems with their levels of conformance based on WCAG 2.0. Nibbler is a free tool for testing websites; it generates a report scoring the website on a scale of 10 for key areas including accessibility, SEO (search engine optimization), social media and technology [126]. Figure 2.7 and 2.8 present screenshots featuring AChecker (Figure 2.7: before testing, Figure 2.8: test results) and Figure 2.9 introduces the Nibbler automated tool. To improve the depth of the present research we extended our automated tests by interviewing users in the framework of a questionnaire.

Despite the fact that both AChecker and Nibbler automatic are very effective, there were a number of cases in which they rather badly affected our research process. Some of the issues that influenced measurement and/or evaluation include test situations in which AChecker or Nibbler being unable to measure and detect certain human needs. Websites with a traditional blind version (yellow letters on a black background), for instance, are not refreshed frequently. Webmasters tend to forget to make new information available, consequently, those websites are likely to contain outdated information. Certain buttons lose their functions over time, which may make users confused. Automatic test tools, to move onto another area, do not measure color vision problems well enough. At times users of low or impaired can hardly read CHAPTA figures (an audio version remedies this problem). Considering further user groups with accessibility issues, blind users or those who have motion problems with their hands use a special keyboard or just the TAB key to navigate. If one button or submenu is not available by the TAB key, the website becomes unsuitable for further use. These are the main aspects that it is necessary to test websites manually, therefore we wanted our experts to investigate in a questionnaire based on our earlier experiences in the field.

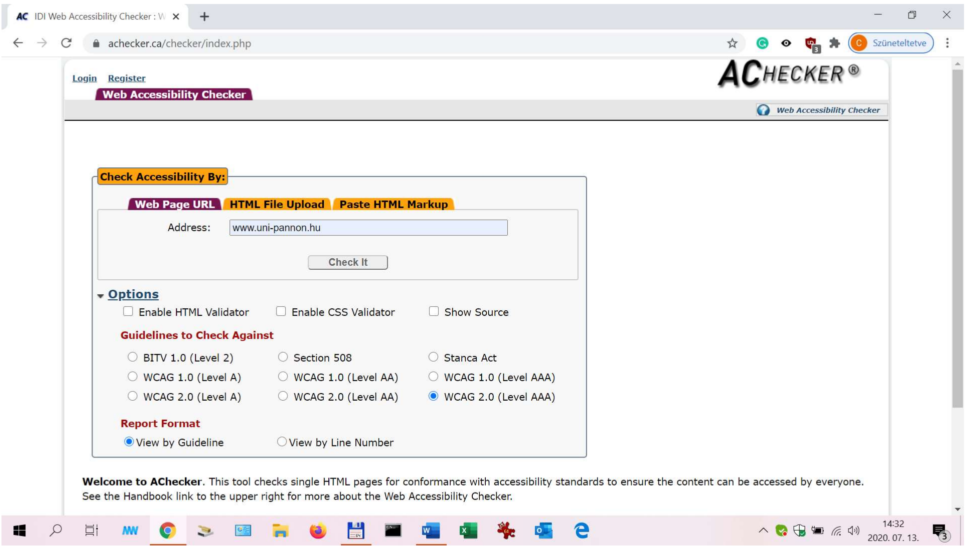


Figure 2.7. Screenshot of the AChecker automated tool (at the beginning of the test)

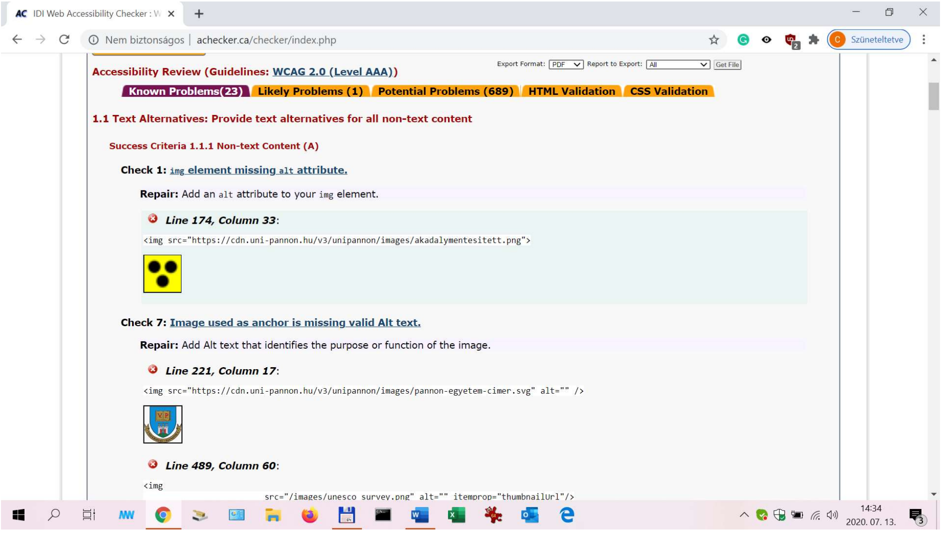


Figure 2.8. Screenshot of the AChecker automated tool (after the test, showing the results)

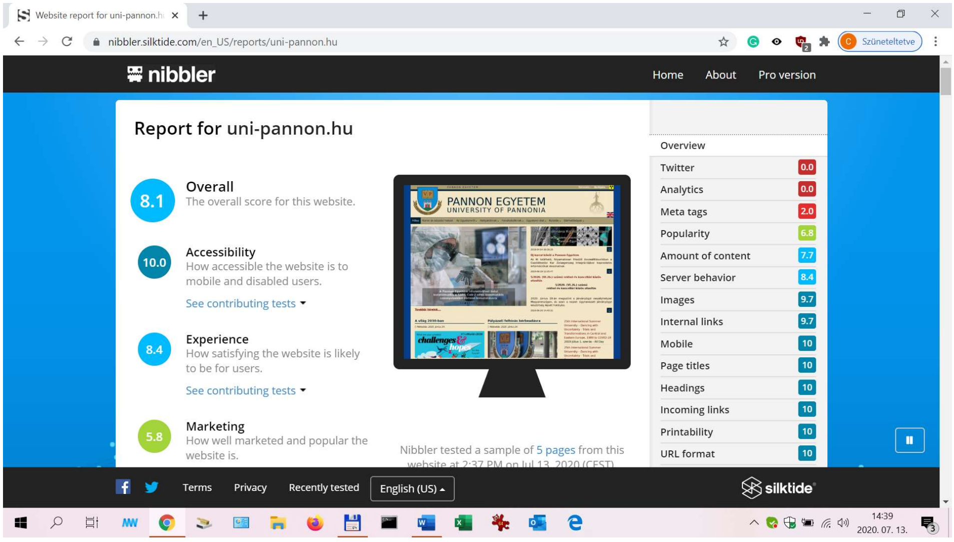


Figure 2.9. Screenshot of the Nibbler automated tool.

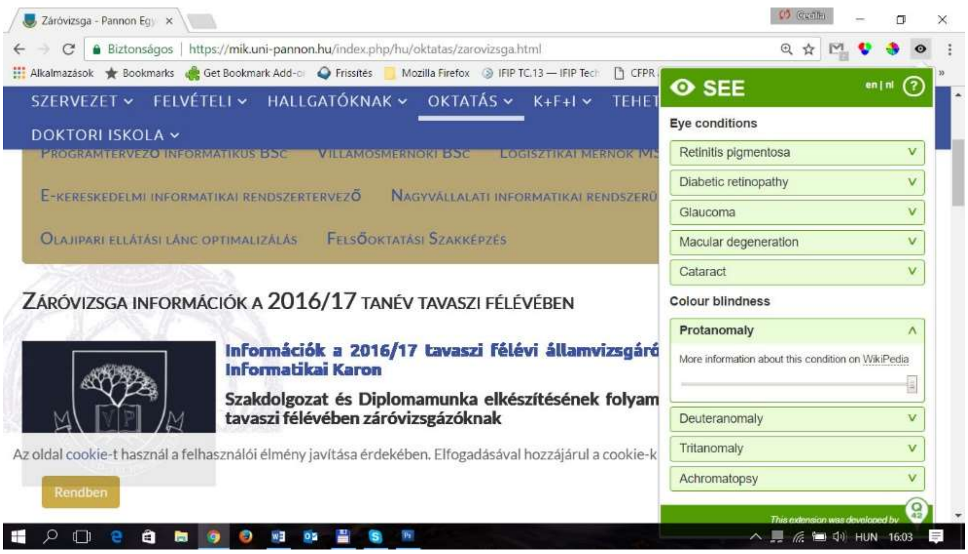


Figure 2.10. WEB-site as it is seen by a colour deficient user with protanomaly.

2.4 Methodological contributions of the theses

I got the results summarised in my Theses using the methods conventionally recognised by a narrower area of specialisation. During my research, I was going for objective tests and measurements whenever I could.

In Chapter 3 for the Thesis group 1, calculations are based on the CIELAB colour space, see Chapter 2.2 Colourmetric fundamentals, mainly 2.2.1 Colour and 2.2.2 Memory Colours of Well-Known Objects subchapters.

Visual-psychophysical experiments can be carried out with the application of different psychophysical methods. The experiments concerning the colour theory are, on one hand, based on objective methods of measurement:

- the use of the Eyedrop tool of Photoshop,
- the application of a measuring instrument: X-rite Eye-One (i1), Minolta, Spectrascan spectrocolorimeter,
- test software developed by my supervised students,
- Microsoft Excel data analytics tool,

and on the other hand, the colour memory tests are based on subjective psychophysical measurement.

As for the fields of Human-Computer Interaction and software ergonomics, I have taken measurements questioning barrier-free design, first, utilising the following: objective methods, test software of my students supervised by me, and an international validation software; and last but not least, I have carried out surveys on the user interface and usability of games made by my students.

In Chapter 4 for Subthesis II/1 my research is based on the WCAG 2.0 [109] standards. For the suggested measurements and testing methodology I have used different colour-blindness simulators: (ASP.NET) [119], (ETRE) [117], (Coblis) [118], ColorOracle (ColorOracle) [120] and the SEE [122] web-application. For automatic testing I used the AChecker [121] testing tool. Moreover, the human investigations were made with the Variantor [123] special glasses by answering a questionnaire. Unfortunately, the AChecker automatic testing tool does not add together the problems by criteria therefore I have developed software for this calculation.

In Chapter 4 for the Subthesis II/2 my research is based on the WCAG 1.0 [108] and WCAG 2.0 [109] standards. For the first research the WebXACT validator [124] and XValid own software [17], and for the second research the AChecker [121], and the Nibbler [126] automatic testing tools were used. In addition, I designed a human questionnaire.

In Chapter 4 for Subthesis II/3 the research is based on the literature review and the above-mentioned testing tools.

I put a great emphasis on how to universalise and scientifically comprehend the typically empirical data and results produced during my research via application or experiment.

- For the analysis of these data, the statistical program package R (R version 3.5.0.) was used.

In addition to basic statistical calculations performed by using the data gained by questionnaires, I investigated the equality of the ratios of the websites satisfying certain conditions. In these cases, hypothesis H0 was the equality of the two proportions and the alternative hypothesis was supported by all other values. For investigating the link between two quantities we applied Pearson correlation coefficients and hypothesis H0 was confirmed with a value of zero as then the independence of the variables is true in terms of their Gauss distribution. Rank correlations were investigated as well by testing the zero value of the Spearman rank correlation coefficient. Finally, clusters were made from the countries to see the similarity in groups. For this purpose, the generally accepted k-means clustering algorithm was applied. All statistical computations were made by the statistical program package R. My recommendations in the Thesis group II is based on these statistical analyses.

In Chapter 5 for the Thesis group III, the research is based on the literature review and my own developed testing questionnaire. The last subthesis III/2 is the practical implementation of the previous subtheses.

I have given thorough description of projects involving international cooperation, laboratory experiments, and methods and questionnaires made for educational and rehabilitation observation in the publications indicated among my Theses. One of my main objectives was how and to what extent may software ergonomic principles be introduced in everyday software design practices.

Since I obtained my Ph.D. the Theses have been completed by new research and new findings. Apart from few publications on the results of our collaborative work with Professor János Schanda, most of the publications feature my collaboration and work as supervisor in connection with B.Sc and M.Sc. students and in one case a PhD candidate. All contributors and co-authors are indicated in the present research.

Particular theses include these publications in a more or less chronological order. I have listed 70 selected original publications (due to length restrictions) produced over the past 1.5 decades, however, there have been several other writings that demonstrate the validity of my hypotheses. (The unlisted publications are available online at MTMT.)

Chapter 3

Colour design for games

This chapter is based on my previous publications: a journal paper [9], two publications in conference proceedings [34, 35] and four book chapters [56-59].

In the first part of this chapter the research of colour measurement of games is analysed.

Illustrated colour of known objects in Virtual Reality (VR) games for various games exhibit characteristic differences. In the first part of our analysis we studied the cartoons' colours, with a great emphasis on whether there are any cultural differences. Coloration of well-known objects depicted in cartoons originating from different parts of the world show characteristic differences. We analysed several soft-copy and hard-copy cartoons form all over the world and determined what colours the designer use for complexion, sky, water, soil, etc. We continued with the study of VR games' colours. We analysed eight game categories' colours and determined which colours the designer used for skin, sky, water, grass, etc. These colours were compared with the prototypical memory colours and cartoon colours of these objects. The research quantifies these differences and provides advice to the VR games to be tinted if they are intended for a specific region of the world and specific VR games. In the second phase of the research such images of films, which were the equivalent of VR games are analysed. The staining of these films was compared to the corresponding colour of VR games and memory colour display object.

In the second part, an investigation of memory colours is described. For this investigation Flash test software was developed. 75 observers used this test software in 4 groups: average elementary school children (aged: 8-9 years), intellectually disabled children (age: 9-15), virtual game addict university students (average age: 20) and university students who play with VR games rarely or never (average age: 20). In this pilot test we investigated the difference of memory colours of these 4 groups.

For the first research detailed quantitative evaluation is performed on more than 10 thousand measurement. For the second research the detailed quantitative evaluation is based on the users' colour choices.

3.1 Colours of VR games

3.1.1. Introduction the colours of VR games

Many books and articles deal with the question of how colours influence the mood of people seeing them and how, e.g. in a picture the mood of a person can be expressed in colours. For artists, colour was always a vehicle to express moods [182]. Panton, as an artist, even gave the title of his booklet: "Choosing colours should not be a gamble. It should be a conscious decision. Colours have meaning and function" [183]. Hutchings [184] discussed the use of colours during the ages and pointed out that there are cultural differences that should be taken into consideration. Robertson and his colleagues [185] found evidence of cultural and linguistic relativity, among others in colour categorization. Analysing ninety-eight languages Berlin and Kay [186] found that eleven colour words act as focal points of all the basic colour words in all languages of the world. This set of eleven seems therefore to be a semantic universal. Basic colour words are translatable. These basic colour terms are in English: red, orange, yellow, green, blue, purple, pink, brown, grey, black and white.

Colour perception has been a traditional test-case of Whorf's principle of linguistic relativity [187,188], i.e., the idea that speakers of different languages perceive and process reality and the world differently, influenced by lexical and grammatical distinctions specific to their language [189]. The vast majority of empirical research in the past 17 years has supported the notion [190] that language acts an attention-directing mechanism in the cognitive processing of colour, in both offline similarity judgments [185,188] and online perceptual discrimination [191-193].

Duncan and Nobs [194] investigated the interrelationship between human emotions induced by colours and their psychophysical stimuli and found differences between emotional colour scales established in Europe and the Far East. Szabo developed predictive mathematical models of colour harmony [195] to quantify colour harmony impression of observers and a new light source quality metric called Harmony Rendering Index [196] based on these formulae.

Multimedia applications usually use graphical drawings instead of photographs, because they can be more efficiently moved and stored. In many of the cases users regard pictures with less colours appropriate for use. For VR games' simulations it is enough to use homogenly designated pictures, like in the programs for treatment of some kinds of phobias. These pictures will henceforward be called cartoon-like pictures, graphical pictures or simply cartoons.

The graphical designer has to choose from a great amount of hues representing qualities. Most of the multimedia programs enable a wide range of choice of colours from its own palette, and also gives some instructions how and where these colours can be used. Previously the colouring of the pictures was the task of the graphical designer, who learnt his profession. Today, this task is made by the IT engineer programming the animation, or more frequently called animator.

The pictures have an aesthetic value as well, which means that the chosen hues cannot clash and that they have to be in a harmony. There are several guiding principles regarding the harmony of colorization.

In our research we give instructions how to set the colours of different qualities (objects). We created a database, which contains hundreds of pictures' colours from different cultural regions. We categorized hundreds of pictures that are paper-based (henceforth hard-copy) or pictures from the internet (henceforth soft-copy) and also, we measured the colours of their different qualities. We evaluated six important and most frequently used qualities (face, grass, sky, lake, foliage, tree-trunk) from four different cultural regions. We compared the results with the memory colours.

The above investigations were performed either on single colour patches or tried to elaborate on historic findings. We were seeking a different way to be able to compare the preferred coloration of well-known objects by present day population – especially young people – coming from different cultural backgrounds. VR games are popular among children and young people all over the world. They are not only popular but have proved effective when used in special education to teach independent living skills [197,198] and more latterly by 'modding' popular games engines (such as the Source engine as used in Half-Life 2) to teach employment skills. [22,199]

A lot of 3D games can be found nowadays. There is a huge difference between the properties of game heroes and the properties of real humans. This difference can be seen in the choice of colours to depict the heroes and their surroundings, which is far from what we can see in our everyday life and our environment. The usage of these computer games by children is getting longer and longer every day. The main question can be, whether the colorization of these games have any influence on the children's colour sense? If we want to answer this question, we have to analyse the input, the colours which are used in games.

The effects of human differences in immersive VR environments are a cutting-edge research topic [200,201]. Inside this area, focusing on cross-cultural aspects is our promising target.

These games are used on PC or laptop. In this case there are non-immerse VR games. The users observe these games under approximately 30° visual angle, thus in this respect it is immaterial that people do not see colours outside of approximately 100° horizontally [202]. Another question is if the player uses these games using a Head Mounted Display (HMD). Field of view (FOV) of the HMD gives the world builder yet more compromises to make. Although theory is limited, narrow FOVs may hinder task performances such as maneuvering, grasping objects and locating moving targets [203]. Wider FOVs may improve performance and also feelings of involvement and presence, but this comes at the expense of greater weight and size of the HMD and possibly worse image resolution [204].

Virtual reality games are popular among children and adolescents around the world. The colouring of the heroes and the environments in VR games are very far from the average person and the real environment. Children play VR games every day, so these games will affect the aesthetics of the children. A question could be: Why are we not paying more attention to the child's experience to ensure the right coloration of virtual worlds: in this context? Do designers and programmers need to pay due attention to these colours in the virtual world, or not?

The hypothesis (HI/1) could be formulated: Virtual worlds are not displayed with realistic colours (i.e. closely resemble real object colours). Cartoon artists and VR game developers use unrealistic colours.

3.1.2.Measuring method

3.1.2.1 Cartoon's picture samples studies

In our investigations we had to restrict ourselves to pictures where the theme of the picture has some resemblance to the real world, i.e. pictures were not considered, where the coloration was far from what one would accept as a "natural" colour of an object.

At the start of our research, we posed the question, where can we find hundreds of pictures that can appear everywhere in the world? How can we map the pictures that were created by graphical designers during the last decades? The solution was to use are the cartoons, both in hard-copy and soft-copy. As a first step we collected hundreds of graphical pictures (henceforth we call them cartoons). To achieve our aim, we tried to categorize them according to cultural regions. The most important categories are the following: European (historical), American (hero, combat), Japanese (so called manga) and Australian (family).

The European carton designers love to depict historical themed stories, here we have also listed the depiction of literary works and situation comedies. These are stories like the French "Asterix and Obelix", or the Hungarian "Mátyás király" (King Matthias, "A Pál utcai fiúk" (Paul street boys), or the English "Tom Sawyer or Huckleberry Finn", etc. Regrettably the real Hungarian cartoon designers have disappeared, however we were able to find a web site (http://rajz.film.hu/), where they wish to restart making the traditional cartoons with a help of project funding.

The Americans prefer completely different types of stories. These are called 'combat' cartoons (Spiderman, Robocop, Superman). In an American cartoon the depiction is completely different from the one we know in Europe. The figures are sketchy; we can feel the movement and dynamics on them. It is interesting to note that in these cartoons the facial and body forms are depicted in the most natural way. The scenery however is not as important, mostly they depict a figure with a simple one colour background. The Europeans however give the background nearly the same prominence as the characters.

The cartoons which are preferred by the Japanese are the most interesting. The Japanese cartoon designers do not present their characters on the basis of their cultural background. The characters, who are mostly children, are tall, have long legs, big colourful eyes and hair, and very pale complexion. On the basis of the previous knowledge, we can unequivocally divide these cartoons from the previous categories.

We assessed some samples from Australia, but we could not really categorize them. So, we created a new category, based on the Australian type (family). The Australian cartoons' characteristics are nearly the same as we find in the European or the Japanese types, the figures and the background are clearly distinct. The scenes are mostly in the present, they are fabular, the colours are natural, there are no unnatural hues, such as people green or purple hair~~s~~.

There are cartoon series that have a global distribution, and where prints are made in different countries. One of these is 'Asterix' that has more the 100 translations. Just to get a feel for ~~on~~ the differences publishers choose for complexion colour we summarized complexion colour of "Cleopatra", one of the cartoon characters in the series No. 6 "Asterix and Cleopatra" depicted in the Cover Galery of Asterix International in Figure 3.2. We just inserted the pictures in a graphics program that enabled "eye-drop" technique to fetch the colour into the program's colour management. As we were interested only in the relative differences between the particular editions, we used the default setting of the program. Table 3.1 shows the results in increasing CIELAB lightness. As can be seen the Swedish and the American editions use low CIE 1976 lightness, in case of the American edition extremely high CIELAB chroma was found. The next higher lightness was found for the Turkish edition, where the CIELAB hue angle is at the reddish extreme. The Hungarian, Russian, Greek and German editions show complexion colours of higher lightness and low CIELAB chroma. The latter two are also between the most yellowish ones.

As we have downloaded the above samples from the Internet, we have no information on eventual distortions produced by the scanner at the input site, neither on the actual state of the pages scanned. Therefore, we do not want to draw major conclusions from this part of the study; it should show only that even for the same fundamental picture if reproduced in different countries colour differences would be seen that might be coupled to the regional preference. To gain ~~a~~ better insight into the regional differences we investigated cartoons received from different parts of the globe, and compared the colouration used for a number of representative objects.

Table 3.1. CIELAB co-ordinates of some complexion colours of Cleopatra in the Asterix and Cleopatra series of the Asterix International Cover Galery

Edition	L^*	C_{ab}^*	h_{ab}^*
Sweden	64	76	42
USA	67	107	46
Turkey	67	71	37
Brazil	70	74	46
Italy	70	76	42
Korea	71	77	48
United Kingdom	74	62	52
The Netherlands	74	84	48
South-Africa	76	64	47
Hungary	78	51	42
Russia	82	50	47
Greece	83	52	67
Germany	85	48	56

3.1.2.2 The investigated representative hard-copy cartoon colours

Cartoons assessed were from Australia, Europe, Japan and the USA. With the help of a small CCD array based spectroradiometer we determined the spectral reflectance properties of small homogeneous patches (approximately 3 mm diameter) using incandescent lamp illumination and 45°/0° measuring geometry. CIELAB values were calculated for D65 illuminant and 2-degree standard observer.

Analysing a high number of cartoons, we determined the coloration of the following objects:

- fair, suntanned and dark complexion,
- black, blond, brown and red hair,
- clouds and sky,

- tree trunk, grass, foliage,
- soil, sand and water (lake),
- concrete.

The data of six object colours follows: complexion, sky, tree trunk, grass, foliage and water (lake). For better visualization Figure 3.1 shows average values and standard deviation ellipses for three-three of the six colours analysed.

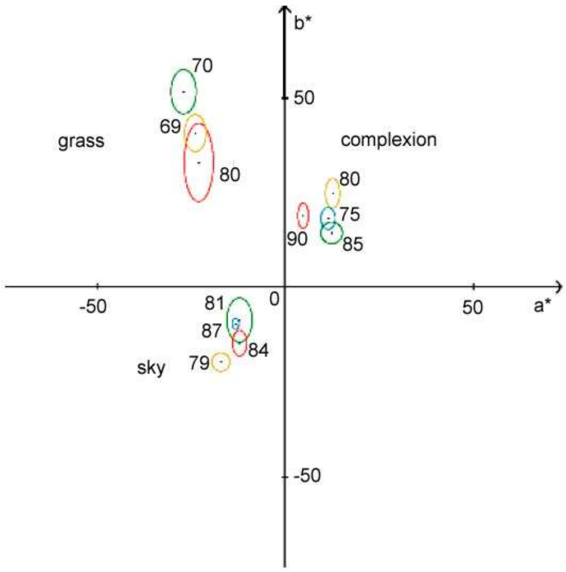


Figure 3.1. Typical complexion, grass and sky CIELAB values, depicted on an a^*, b^* diagram, L^* values are written in the vicinity of the standard deviation ellipses, shown in blue for American, in green for Australian, in red for Japanese and in yellow for European hard-copy cartoons.

As an example, we can see one edition of Asterix's (original) cover (Figure 3.2).

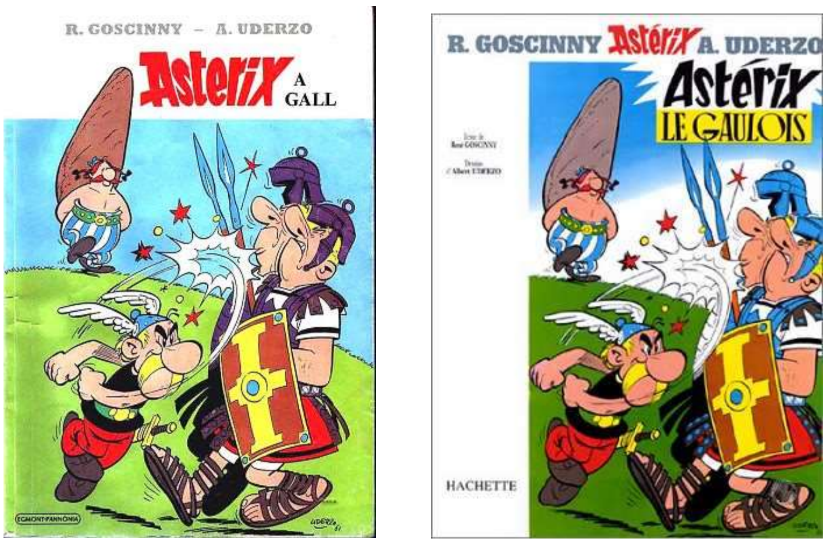


Figure 3.2. Cover released in Hungary (left side) and cover from France (right side)

3.1.2.3 Representative soft-copy cartoon colours

Similar investigations as described in the previous paragraph were performed on additional cartoon pictures found on the Internet. The only difference in this case was that the CIELAB co-ordinates were not measured in our laboratory. We supposed that the cartoons were put onto the Internet using sRGB colour space, and thus we have set our graphics program to this default state and determined the CIELAB co-ordinates using the eye-drop facility of the program. Here again we show in Figure 4 average CIELAB values and standard deviation ellipses for three-three of the analysed six colours.

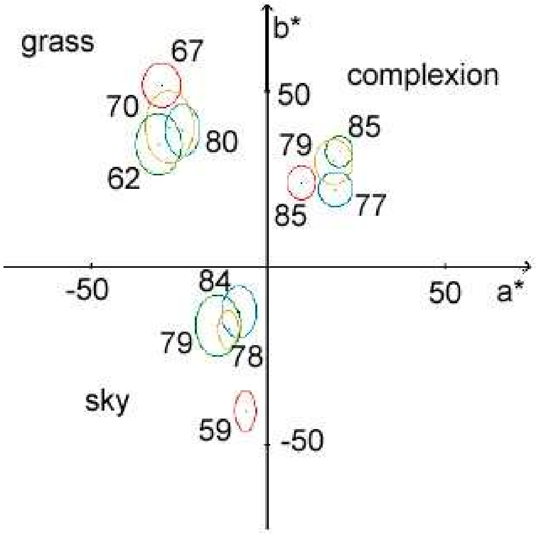


Figure 3.3. Typical complexion, grass and sky CIELAB values, depicted on an a^*, b^* diagram, L^* values are written in the vicinity of the standard deviation ellipses, shown in blue for American, in green for Australian, in red for Japanese and in yellow for European soft-copy cartoons.

Table 3.2 Numerical data of hues of objects on the Hungarian and French covers

Object		L^*	a^*	b^*
Grass	HU	80	-36	59
	FR	50	-36	52
Sky	HU	88	-27	-18
	FR	69	-10	-46
Face	HU	87	12	23
	FR	73	34	35
Rock	HU	57	34	22
	FR	57	15	4
Moustache	HU	96	-14	79
	FR	88	-3	82

In Table 3.2 we can see the differences in use of hue between the two pictures. One of the most noticeable differences is that the Hungarian copy uses lighter colours. During the analysis of the grass colour there is was not a great difference between the a^* and b^* value. However, the other values show some characteristic differences, the “Hungarian” sky is greenish, the rock is brownish. The French face is reddish and darker.

According to the data shown above, we can assess, that we can get realistic results from the measurement of the hues of objects, if the models were made in equal conditions. For this reason, we collected cartoons from other parts of the world. We collected cartoons from Australia, Japan, Korea, America, and France. Unfortunately, there are no cartoons on the market that has been drawn and printed in Hungary. We decided not to analyse cartoons of twenty years or older as the quality of paper and the printing technologies have changed so much over the past decades, and our results could not be compared with the results from the cartoons, that we received from the other countries. To conclude, we only measured the parts of pictures from original cartoons.

3.1.2.4 Measuring the colours of VR games

Most popular virtual games were categorized into eight groups, as can be seen in Table 3.3. Pictures have been downloaded from the Internet of 89 VR games: 7-10 pictures from every game, altogether 752 pictures. Movie films, corresponding to the above films have also been analysed, 179 pictures from 20 films have been downloaded from the internet. The category of games we used in our research is shown in Table 3.3.

Table 3.3. Categorization of the most popular virtual games

Name of the game category	Number of the game category	Number of the film category
Action, Adventure, Mystery Games	AAM	F-AAM
Children's Games	Child	F-Child
Driving & Racing	D&R	-
First-person Shooters	FPS	F-FPS
Simulations	Sim	-
Role-playing Games	RPG	F-RPG
Strategy	Strat	-
Sports	Sport	-

3.1.2.5 Games categories

Title of games, from which pictures were taken are listed.

Action, Adventure, Mystery Games
Tomb Raider 7
Silent Hill 4: The Room
Alone in The Dark: The New Nightmare
GTA San Andreas
Resident Evil 4
Legend of Zelda: The Twilight Princess

Children's Games
Fame Academy: Dance Edition
Camgoo + Webcam
Shrek 2 Team Action
Jimmy Neutron Boy Genius
Robots
Spongebob Squarepants:

Myst V: End of Ages
Syberia II
The House of the Dead III
Monkey Island 4

Battle for Bikini Bottom
Harry Potter
Quidditch World Cup – Classic

Driving & Racing
Need For Speed Underground II
Nascar 2005: Chase for the Cup
Colin McRae Rally 2005
TOCA Race Driver 2
Gran Turismo 4
Driv3r
Hot Wheels Stunt Track Challenge

First-person Shooters
Counter-Strike Source
Day of Defeat Source
Battlefield 1942
Medal of Honor Pacific Assault
James Bond 007: Nightfire
Call of Duty
Doom 3
Unreal Tournament
Maxpayne II
Star Warp Rep. Commando

Simulations
Sim City 4
The Sims 2
Microsoft Flight Simulator 2004
Animal Crossing (Game Cube-ra)
Will of Steel
F/A-18: Operation Desert Storm
Pacific Fighters
IL-2 Sturmovik - Forgotten Battles

Role-playing Games
Final Fantasy X – XII
World of Warcraft
Lineage II
Ragnarok Online
Ultima Online Samurai Empire
Guildwars
Chrono Cross

Strategy
Cossacks II: Napoleonic Wars
Warcraft III (The Reign of Chaos
- The Frozen Throne)
Heroes of Might and Magic III – IV
Rome: Total War
Blitzkrieg II
Age of Mythology
Warlords 4
Warhammer 40k
Imperial Glory

Sports
Ski Racing 2005
MVP Baseball 2005
NHL 2005
FIFA 2005
NBA Live 2005
Fight Night Round 2
Madden NFL 2005
Tiger Woods PGA Tour 2005

3.1.2.6 Film categories

Action, Adventure, Mystery
Lara Croft: Tomb Raider
Lara Croft and the Cradle of Life:
……Tomb Raider 2
Silent Hill
Alone in The Dark
Resident Evil
Resident Evil: Apocalypse

First-person Shooters
James Bond: The World is Not Enough
James Bond: Die Another Day
Doom
Star Wars: Episode I - The Phantom Menace
Star Wars: Episode II - Attack of the Clones
Star Wars: Episode III - Revenge of the Sith

Children's
Shrek
Shrek2
Robots
Harry Potter and the Sorcerer's Stone
Harry Potter and the Chamber of Secrets
Harry Potter and the Goblet of Fire
Harry Potter and the Prisoner of Azkaban

Role-playing
Final Fantasy: The Spirits Within

3.1.2.7 Samples studies

We selected objects to be measured for example skin (Caucasian face skin, African skin), hair, sky, grass, trunk, cloud, water (lake, river, sea), brick, concrete (road) and so on. During the investigations we wanted to stay within the boundary of the theme of pictures, where we have some resemblance to the real world, i.e. pictures where the coloration would not be accepted as a "natural" colour of an object, were not considered, i.e. where a specific state of the mind of the hero (e.g. greed, anger, etc.) were emphasized by the designer of the game.

The pictures from the virtual games, which we analysed, were downloaded from the Internet, an assumption was made that these pictures were calculated for the Internet using sRGB colour space. Our measurements were taken in the CIELAB colour space. Sample Tool of Adobe Photoshop was used for sampling (Figure 3.4). Of L^*, a^*, b^* values nearly 4500 determinations were made. h_{ab} hue angle and its standard deviation (Δh_{ab}) was calculated ($h_{ab} = \arctan(b^*/a^*)$), together with the chroma (C_{ab}) and its standard deviation, from the L^*, a^*, b^*, which enabled to determinate the changes in dimensions near to those of perceptions.

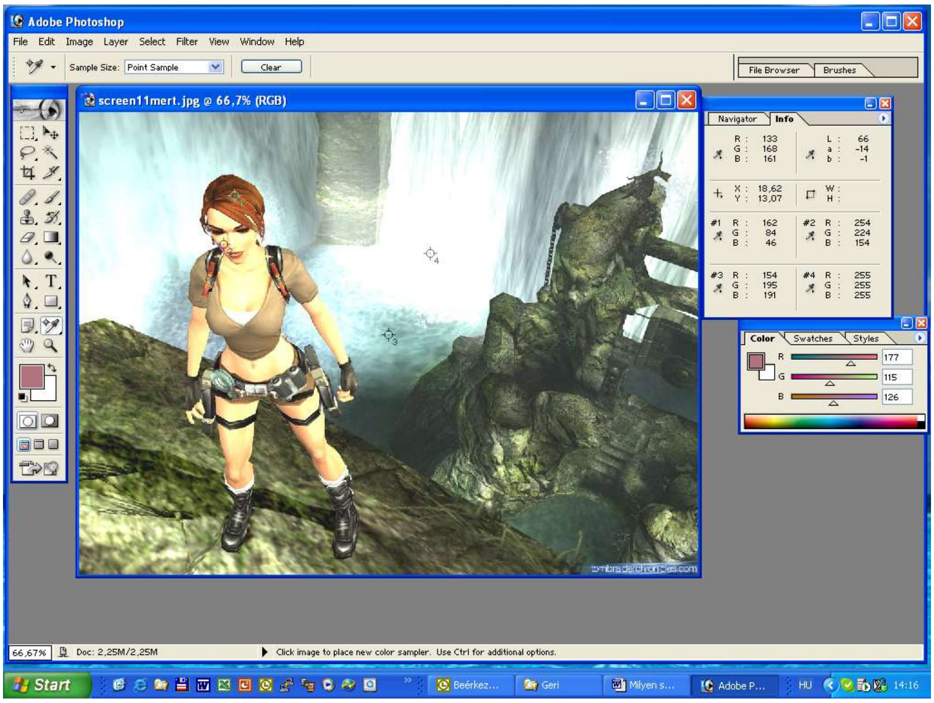


Figure 3.4. Colour measurement in Photoshop, using the eye-drop tool, example is the Tomb Raider play. 1st measurement point: red hair, 2nd measurement point: bright face, 3rd measurement point: water, 4th measurement point: whitest point in the picture.

Tables 3.4-3.7 show the average CIELAB L^*, a^*, b^*, h_{ab} and Δh_{ab} values by game and film category. (Where the value is missing, there was no appropriate sample.)

Table 3.4. The average RGB, CIELAB L^*, a^*, b^*, h_{ab} and Δh_{ab} values by game category

Measured objects	Game Category	R	G	B	L^*	a^*	b^*	h_{ab}	Δh_{ab}
caucasian face skin	AAM	189.76	151.41	121.17	65.12	13.32	21.83	60.82	15.80
	Child	226.10	180.76	144.10	76.67	14.00	25.38	73.38	64.90
	D&R	182.00	114.00	91.00	55.00	26.00	25.00	43.88	
	FPS	154.65	115.50	89.74	51.44	13.56	20.29	57.23	21.86
	Sim	221.83	158.00	119.33	71.00	22.00	31.00	54.80	4.72
	RPG	212.40	156.13	122.80	69.93	18.93	26.67	56.49	9.07
	Strat	244.00	197.00	141.00	83.00	12.00	35.00	71.08	
	Sport	177.18	126.09	105.05	57.18	18.59	19.91	46.43	10.09
african face skin	AAM	102.00	67.00	46.71	32.14	13.57	18.57	55.41	11.19
	Child	150.00	115.00	59.00	51.00	9.00	36.00	75.96	
	D&R								
	FPS	86.00	68.50	53.50	32.00	6.50	12.00	70.45	27.64
	Sim								
	RPG								
	Strat								
	Sport	118.62	81.03	62.10	38.38	14.31	17.74	51.11	8.31
sky	AAM	126.67	146.90	166.04	59.53	-1.71	-12.43	221.30	74.10
	Child	72.43	152.04	204.87	60.17	-7.91	-33.39	253.03	27.88
	D&R	104.56	135.10	170.87	54.60	-3.08	-22.66	257.56	23.92
	FPS	145.47	161.53	178.97	65.17	-2.37	-11.03	226.39	75.98
	Sim	138.79	165.91	217.18	67.42	0.36	-29.39	270.51	8.05
	RPG	114.60	149.64	202.64	61.12	-0.68	-31.04	266.48	17.88
	Strat	141.59	177.91	213.64	70.95	-5.32	-22.14	256.80	17.76
	Sport	105.50	138.30	184.60	56.00	-1.10	-28.30	265.52	18.25
trunk	AAM	109.65	102.25	79.25	43.00	0.35	14.10	119.24	75.55
	Child	110.42	80.67	45.17	37.00	9.83	25.58	73.13	30.70
	D&R	90.08	79.65	68.73	34.08	3.35	8.15	95.86	70.31
	FPS	96.20	84.60	68.40	34.87	3.07	11.07	70.45	16.32
	Sim	101.20	80.20	76.40	34.80	8.40	5.60	96.47	112.69
	RPG	114.43	92.61	65.00	41.70	6.43	19.35	82.28	61.77
	Strat	100.33	82.33	54.00	37.00	4.00	21.33	80.48	5.96
	Sport								
cloud	AAM	198.47	205.88	198.28	81.78	-3.03	3.28	166.25	81.39
	Child	180.13	196.25	205.50	78.13	-3.88	-6.75	195.67	83.10
	D&R	206.38	209.73	215.25	83.34	-0.04	-3.07	215.60	85.05
	FPS	212.59	203.47	195.41	82.56	2.53	5.44	124.17	96.50
	Sim	191.89	196.44	210.07	79.11	0.52	-7.22	255.97	59.80
	RPG	212.37	213.73	218.53	85.57	0.67	-2.57	224.25	83.88
	Strat	213.60	216.52	215.52	85.84	-0.80	0.36	199.27	87.12
	Sport	198.00	201.79	212.58	80.84	0.47	-5.79	231.76	78.63
grass	AAM	99.20	108.13	52.40	44.47	-9.60	28.57	108.40	15.97
	Child	56.26	101.05	31.05	38.26	-25.42	32.26	128.17	8.91
	D&R	102.77	105.73	63.50	42.92	-6.04	23.04	105.62	9.79
	FPS	94.64	94.39	55.04	38.79	-4.07	21.93	101.27	8.40
	Sim	82.20	109.32	55.09	43.57	-15.50	26.86	116.29	15.69
	RPG	76.28	91.33	35.83	36.25	-12.85	28.80	114.55	11.82
	Strat	87.57	104.43	38.01	41.73	-13.84	32.90	112.45	12.19
	Sport	90.63	114.80	48.61	44.85	-17.37	32.46	118.74	8.89
foliage	AAM	89.43	108.95	67.67	44.62	-11.76	20.10	126.38	44.85
	Child	90.54	135.46	47.69	49.31	-24.77	39.00	122.57	13.75
	D&R	84.38	94.67	60.90	40.60	-8.58	17.63	119.44	18.48
	FPS	103.50	105.18	70.95	42.45	-4.45	17.73	103.95	20.22
	Sim	83,44	99.89	47.56	41.94	-11.94	27.50	113.19	16.36
	RPG	78.68	103.27	48.30	41.73	-15.38	26.86	119.10	15.66
	Strat	68.94	101.90	33.23	37.88	-19.83	32.83	119.63	10.57
	Sport	84.22	98.89	64.67	38.78	-10.89	18.78	120.07	8.78
water	AAM	129.27	155.50	150.45	59.23	-6.23	1.05	177.35	81.93
	Child	64.00	97.67	167.67	42.00	4.67	-40.00	261.38	37.99
	D&R	59.50	100.50	161.50	43.00	2.50	-36.00	254.41	34.24
	FPS	163.67	164.33	172.00	67.00	1.33	-0.33	117.84	124.65
	Sim	72.43	95.48	146.05	40.71	6.52	-29.67	261.74	43.06
	RPG	28.05	64.52	96.48	26.57	-2.14	-22.57	244.67	39.23
	Strat	42.50	101.62	125.08	40.42	-11.42	-18.54	220.93	44.14
	Sport	34.00	82.00	118.00	26.00	-5.00	-26.00	259.11	

Table 3.5. The average hair colours in the CIELAB L^*, a^*, b^*, h_{ab} and Δh_{ab} values by game category

Measured objects (hair)	**Game Category**	**R**	**G**	**B**	***L****	***a****	***b****	h_{ab}	Δh_{ab}
brown	AAM	117.78	99.63	74.37	43.07	4.85	17.19	71.94	11.76
	Child	116.73	69.87	35.40	34.73	17.93	28.33	55.62	11.89
	D&R								
	FPS	94.75	66.25	36.25	30.25	10.25	22.25	63.59	10.50
	Sim	104.50	65.75	51.75	27.50	14.75	14.25	43.88	2.92
	RPG	108.80	75.40	48.80	32.80	11.60	22.00	66.21	12.23
	Strat								
	Sport	74.60	54.40	41.20	27.40	8.00	12.40	56.38	13.57
blond	AAM	185.89	144.26	90.31	60.11	11.97	34.17	71.45	13.6
	Child	225.00	202.00	133.67	79.33	4.33	36.67	77.34	20.97
	D&R	79.00	99.00	50.00	39.00	-15.0	25.00	120.96	
	FPS								
	Sim	209.00	176.00	131.00	71.00	8.00	28.00	74.05	
	RPG	208.75	176.00	111.75	74.25	6.75	39.25	81.48	12.05
	Strat				76.00	3.00	43.00	86.01	
	Sport								
black	AAM	30.55	28.73	24.55	11.09	0.82	3.45	142.84	96.13
	Child	20.33	20.33	16.33	7.00	-0.33	2.00	97.63	36.89
	D&R	29.00	22.75	21.75	9.75	2.75	1.50	46.84	37.40
	FPS	26.05	19.48	15.67	7.57	2.95	3.62	73.89	55.80
	Sim								
	RPG	41.00	41.00	53.00	16.00	2.67	-7.33	188.64	126.72
	Strat								
	Sport	29.10	23.05	19.19	8.86	2.48	3.33	104.66	88.87
red	AAM	114.43	66.21	40.00	33.36	19.36	25.29	54.88	9.76
	Child	115.33	39.67	19.50	27.83	32.50	30.50	42.91	3.11
	D&R				21.00	22.00	21.00	43.67	
	FPS	82.00	33.00	18.00					
	Sim	204.00	90.67	45,67	54.33	43.33	48.00	47.84	2.39
	RPG	154.75	71.25	40.50	41.00	34.00	33.00	39.32	22.53
	Strat								
	Sport								
grey	AAM	225.00	183.00	171.00	79.00	14.00	12.00	40.6	
	Child								
	D&R								
	FPS								
	Sim				69.00	6.00	7.00	49.40	
	RPG	136.00	126.00	135.00	54.00	5.00	-3.00	329.04	
	Strat								
	Sport	193.67	175.67	160.00	70.67	5.00	10.67	57.97	18.97

Table 3.6. The average *L*, a*, b** coordinates as well as the calculated h_{ab} and its scatter (Δh_{ab}) values for the most important six parts of the picture for each film which has a corresponding game

Typical part of the picture	Game category	R	G	B	*L**	*a**	*b**	h_{ab}	Δh_{ab}
aucasian face skin	F-AAM	200.95	151.91	130.13	67.09	17.09	19.27	64.85	70.77
	F-Child	201.33	158.51	141.67	69.08	15.00	15.62	65.97	71.85
	F-FPS	177.49	128.58	100.07	58.05	17.00	23.30	52.91	12.17
	F-RPG	148.71	113.71	102.43	50.57	13.71	12.71	78.96	92.58
frican face skin)	F-AAM	127.00	93.00	81.00	43.00	13.00	13.00	45.00	
	F-Child								
	F-FPS	120.20	90.20	71.60	40.20	11.20	16.00	52.84	16.89
	F-RPG								
sky	F-AAM	243.00	239.50	252.50	95.00	3.00	-5.50	281.12	53.30
	F-Child	129.15	176.92	222.85	70.23	-5.08	-28.38	241.57	54.74
	F-FPS	153.78	177.44	197.89	70.78	-2.78	-13.89	224.82	59.94
	F-RPG	179.33	172.33	197.00	71.67	6.33	-11.67	295.82	22.71
tree trunk	F-AAM	127.00	111.00	95.50	48.00	4.50	11.00	67.79	3.15
	F-Child	103.20	89.00	67.50	38.40	3.80	14.50	96.38	80.66
	F-FPS								
	F-RPG								
cloud	F-AAM								
	F-Child	203.44	207.22	209.56	82.78	-0.22	-1.44	168.13	94.70
	F-FPS	232.00	203.00	173.00	83.50	7.50	19.00	69.72	6.14
	F-RPG								
grass	F-AAM	92.67	90.67	64.67	37.67	-2.33	15.33	99.01	5.08
	F-Child	118.13	131.93	52.87	52.47	-13.47	39.20	110.22	15.84
	F-FPS	170.00	191.00	86.00	74.00	-19.00	49.00	111.19	
	F-RPG								
foliage	F-AAM	180.67	198.00	160.67	77.67	-10.67	17.00	131.51	42.16
	F-Child	104.13	113.00	51.19	45.75	-10.31	32.00	109.95	18.73
	F-FPS								
	F-RPG								
lake	F-AAM	144.00	167.00	176.00	67.00	-7.00	-7.00	225.00	
	F-Child	55.00	107.67	115.67	42.67	-13.00	-9.33	205.18	27.19
	F-FPS	159.00	153.00	153.00	64.00	2.00	1.00	26.57	
	F-RPG								

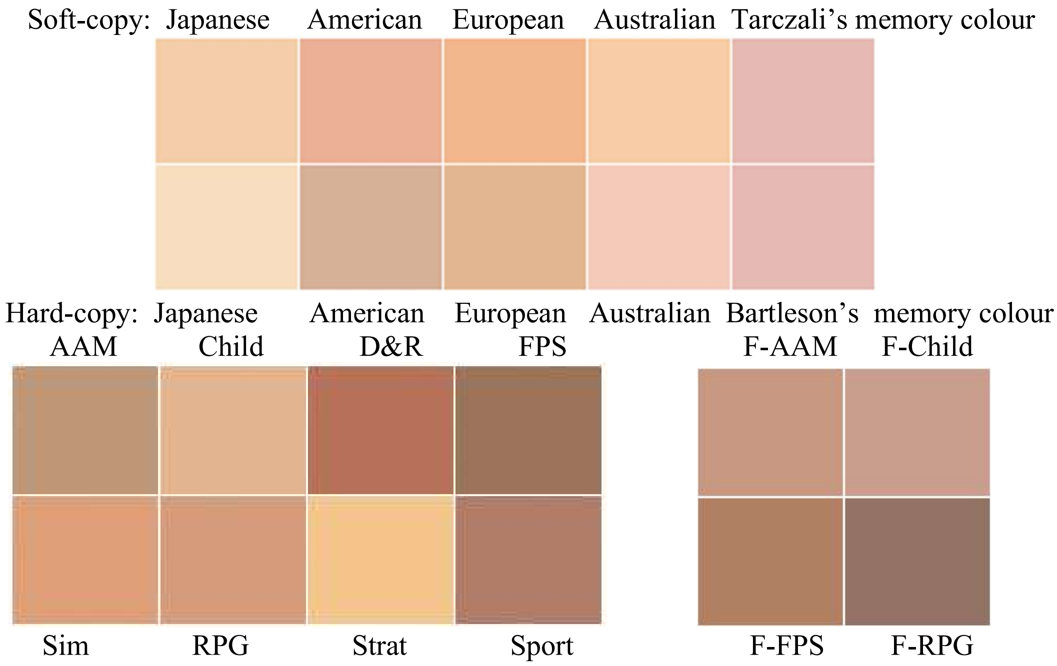
Table 3.7. Average L^*, a^*, b^* and h_{ab}, Δh_{ab} values of hair colours in the different film categories

Typical part of the picture	Category of the play	R	G	B	L^*	a^*	b^*	h_{ab}	Δh_{ab}
brown	F-AAM	136.67	104.76	75.05	46.71	10.57	21.81	64.80	7.23
	F-Child	81.89	73.50	65.44	31.78	3.00	6.56	92.56	83.31
	F-FPS	103.15	77.67	58.15	34.81	8.89	15.48	66.25	51.96
	F-RPG	61.83	46.83	34.33	20.67	5.83	10.33	65.92	18.73
blond	F-AAM								
	F-Child								
	F-FPS	179.00	157.33	127.33	65.67	5.00	18.67	72.79	13.53
	F-RPG								
	F-AAM	40.15	31.74	29.47	13.38	4.32	2.74	135.23	107.38
black	F-Child	27.50	25.83	27.50	9.50	1.50	-0.67	101.72	94.69
	F-FPS	20.69	16.44	18.13	6.19	2.25	-0.44	156.42	132.70
	F-RPG								
	F-AAM								
red	F-Child	137.62	87.54	55.69	42.31	19.08	26.77	51.41	15.02
	F-FPS								
	F-RPG								
	F-AAM								
grey	F-Child	161.00	149.00	122.00	61.50	1.50	16.50	86.10	11.30
	F-FPS								
	F-RPG								

3.1.3 Discussion of colour of games

It seems that comparing the choice of colours used in virtual games [59] with the colours used in cartoons and the so-called prototypical colours, which people mentally link with the colours of some objects, are of great interest. We compared results of studies by Sik Lanyi and co-workers [34], who investigated the usage of colour shades in cartoons all over the world, with the colours of objects in our research, and with the ones determined by Tarczali [115] and Bartleson [114] for memory colours. Sik Lanyi [9] found that there are characteristic differences between both of hard and softcopies (i.e. printed cartoons and downloaded images from the Internet) of cartoons originating from different parts of the world [59].

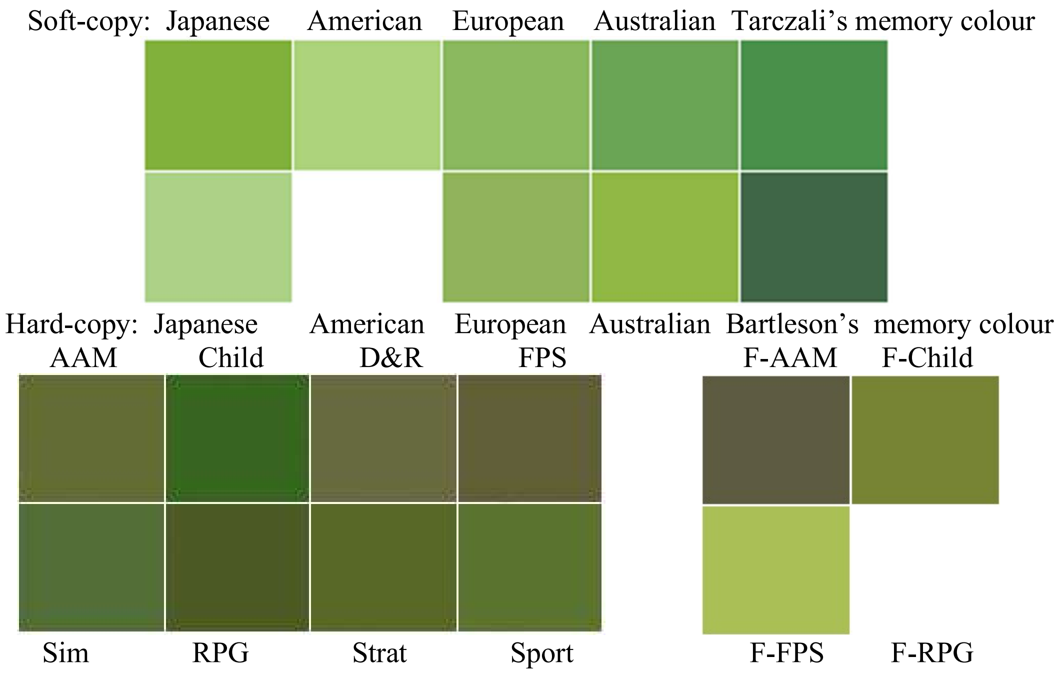
Complexion colour: The lightest of all complexions is the Japanese, followed by the Australian. The darkest complexion colour is the American both in soft- and hard-copy. Interesting facts is that the Japanese uses the palest and the least reddish colour scale of all. We can observe that the memory colour is much more pinkish than the cartoons use for depicting complexion colours. For depicting a sun tanned complexion, we could find nearly the same tendency, where the Japanese is the lightest and its chromaticity is closely related to the European one, and the Australian is the pinkest. The memory colour is the darkest. Average games use a more yellowish colour than the cartoons and the memory colours. The most beautiful face colours were found to be the Child, Sim and Strat face colours. The others use colours that are far from the memory colours. The colours which correspond to the natural complexion colours are used in Child, Sim and Strat games, while the other games use a scale, which are very far from memory colours.



Our measured average Caucasian complexion colours.

Figure 3.6. Comparison of the Caucasian complexion colours

In the films a much larger scatter was found among the different samples, but the average values did not deviate much from the game samples, in most cases they were slightly lighter, an exception was the F-RPG, where the average value of the Caucasian complexion colour turned out to be much darker than in the games. As we had only had one such film in our database, with some very special scenes, from this no direct conclusion can be drawn (Figure 3.6 and Figure 3.9-3.10).

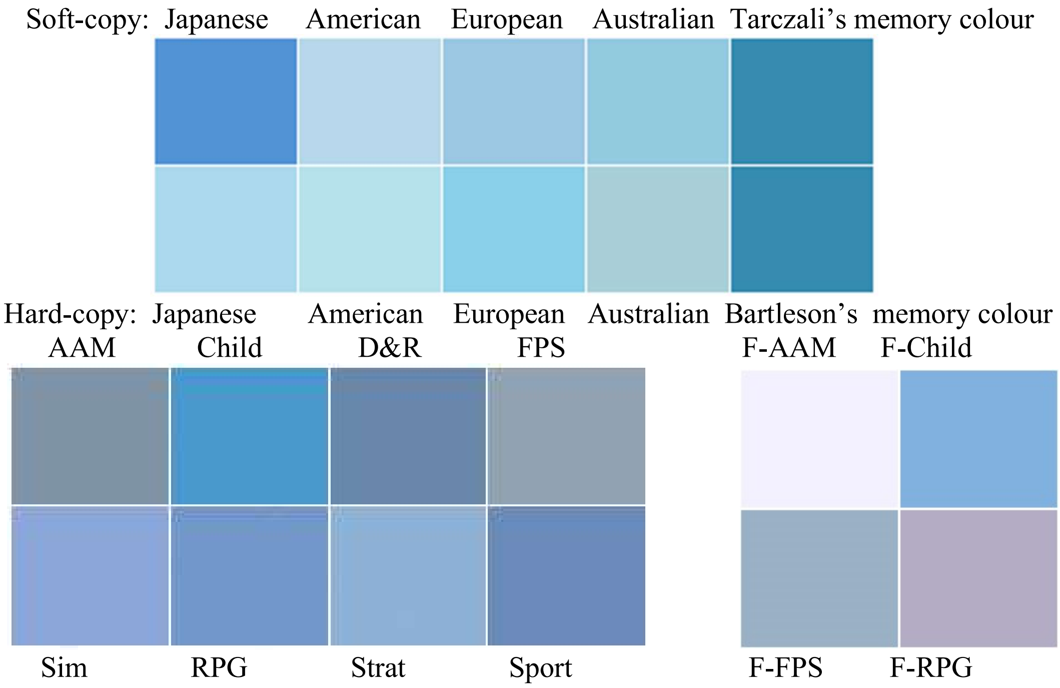


Our measured average grass colours.

Figure 3.7. Comparison of the grass colours

Grass colour: For the colour of grass colour, we can also see several differences. The soft-copy grass colour of the Japanese is much darker than the one of the hard-copy. The Americans and or the Europeans do not use such a yellow shade as the Japanese and the

Australians. The memory colours, as well as the cartoon colours are all lighter determined in the mentioned two groups. The average colours of the grass in the virtual games are shown in the lower row. The only acceptable grass colours are Child and Sport. The others are more brownish than the memory colours. As for the film colours, most of the grass and foliage samples were of background values, which produced in the F-AAM category very dark colours, but e.g. in F-Child and F-FPS films the colours of the grass correspond to the real life grass shade (not withstanding the colours in games, the lightness was higher, resembling the real grass hue, which is, despite the memory colour, more yellowish. Figure 3.7 and Figure 3.9-13.0).



Our measured average sky colours.

Figure 3.8. Comparison of the sky colours

Sky colour: In the case of sky colours the cartoon designers use a much lighter hue, than the memory colour. The only exception is the Japanese soft-copy, which uses a quite dark shade. The sky colours used at the AAM and FPS are very grey. Films usually use a brighter colour than the equivalent games, which is in the case of F-AAM almost white. In F-RPG the hue angle turned out to be extremely violet (Figure 3.8 and Figure (3.9-3.10).

3.1.4 Summary and conclusion of colour of games

Characteristic differences were found between the uses of colours for well-known objects in the different global regions. Designers can use these results if they have to prepare e.g. multimedia presentations for different observers.

In Japanese cartoons prepared for Internet presentation, stronger, more saturated colours are used, sometimes with lower lightness. In Europe the paler colours are preferred. This is true for most objects, except for complexion, where the Japanese use the palest colours and, but it is interesting that the hue angle is larger than the one found in European complexion colours.

The situation is different in the case of printed cartoons. In print the Japanese use paler colours, and the most vivid colours are found in Australian pictures. American cartoon artists do not often try to use colours that resemble those of real-life objects. The prototypical memory colours are in most cases much darker then the colours used in the cartoons.

Figure 3.9. The same picture coloured according to the style used in different game categories: upper range: AAM, Child, D&R, FPS, lower range: Sim, RPG, Strat, Sport

Different virtual reality games show some characteristic differences in the use of colours for some well-known objects. Our results are visually presented with the help of some pictures. We took a picture from a book for outline drawings for painting, where the objects, whose colours were investigated (wood, grass, sky, etc.) were available, and painted it with Photoshop, to help the visualization of the colourimetric data. We coloured these pictures according to the different game categories (Figure 3.9) and film categories (Figure 3.10)

Looking at the pictures one has to consider the following: we used the most usual sky colour for painting the sky, cloud colour for clouds, tree trunk colour for tree trunks, foliage colour for leaves of bushes and trees, grass colour for grass, and also the little pond on the lower right corner was painted with the average water colour for every given game type. The girl on the left side of the picture was painted with the Caucasian complexion colour, and the girl on the right side with the complexion colour found for Afro-American persons was used. (Objects left white in the pictures do not serve enough examples to investigate.) In the cases of AAM and FPS game categories it is very interesting, that the colour of the water in the right lower corner brings to mind the colour of concrete road not of water, the sky is rather grey than blue, and the colours of grass and foliage are basically of same hue. Also observe the differences in foliage and grass as well as soil, sand, sky and water colours.

We note that from the materials researched it appears that most frequently, the designers of these virtual games did not take the use of natural colours into consideration or the use of memory colours.

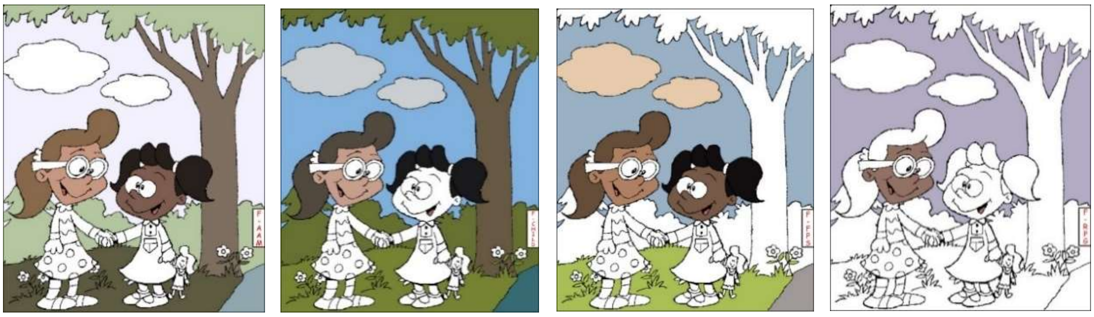


Figure 3.10. The same picture coloured according to the style used in different film categories: F-AAM, F-Child, F-FPS, F-RPG

During the investigations we found that designers use colours to emphasize the message of scenes, and the heroes' state of mind, and appear not to consider researching and using colours which harmonize with the colours of real world.

In most virtual games we see the use of fake colours (colours used out of context to the natural world and common experience or expectations). [9], [34], [59]. We would also like advice the designers of virtual games to use more natural shades of colours, which are more related to real ones.

To conclude graphic designers of online media can now see that there is a drift away from natural colours. This may have been in the past the limitations of technology to control colour? But now designers have much more control of colour and can use your research to be in line with regional colour preferences and nature or purposefully use an alternative colour palette.

Based on the measurement and the analysis HI/1 can be accepted, and I formulate the **Subthesis I/1. According to the tests, I have found that cartoon artists and VR game developers use unrealistic colours. [9], [34], [56-59]**

3.2 Investigating of memory colours

3.2.1 Introduction investigating of memory colours

One of the most influential aspects on the quality of our lives is colour. Our use of memory colour occurs so often we usually don't even realize it is happening [205]. Another important impact colour has in our lives is on our learning processes. Disorders such as dyslexia are sometimes affected by colour. According to a web page on the testing of dyslexia the 'glare' of the white paper makes it hard for some dyslexic children and adults to read the page (Dyslexia, 2002). [206].

"The computer gaming industry has now surpassed the "Hollywood" film industry in total entertainment market share, and in the USA sales of computer games now outnumber the sale of books." (Doug Lowenstein, President, Interactive Digital Software Association) [208].

What is computer and video game addiction?

When time spent on the computer, playing video games, or cruising the Internet reaches a point that it harms a child's or adult's family and social relationships, or disrupts school or work life, that person may be caught in a cycle of addiction. Like other addictions, the computer or video game has replaced friends and family as the source of a person's emotional life. Increasingly, to feel good, the addicted person spends more time playing video games or searching the Internet. Time away from the computer or game causes moodiness or withdrawal [209].

We are seeing more and more adults and adolescents struggling with real world relationships because of virtual world relationships they have created [210].

The Smith and Jones Wild Horses Center has the very first outpatient addiction treatment program for problem gamers in Europe. *"Computer and video games can be fun and innocent. Most people can play computer games without trouble. However, 20% of all gamers can develop a dependency on gaming. Many of these individuals have neglected family, romance, school, and jobs; not to mention their basic needs such as food and personal hygiene? All for a video or computer game"*. [211]

Virtual reality games are popular among children and young people all over the world. There are a lot of 3D games nowadays. The properties of the heroes of these games are, however, very far from those of humans. Sometimes the surroundings are futuristic too. Children play with the computer games longer and longer every day, and thus the games have an influence on the aesthetic sense of the children. In this respect the question might be raised: are the memory colours of virtual game addict people influenced by VR games' colour, or not?

We know that the colour, shape and the name of objects are storing in different parts of the brain. Brain stores knowledge and colour separately [212]. Therefore, the other question was to investigate in this pilot study whether a child with some intellectual disability or learning problems has other memory colours as the average children, or not?

H I/2. The unrealistic colours of VR worlds influence our memory colours. The memory colour of the intellectually disabled students, non-gaming students, and VR addicts are different.

3.2.2 Method of memory colour research

A Flash test software was developed for the investigation of memory colours [213]. 75 observers used this test software in 4 groups: 20 average elementary school children (aged: 8-9 years), 10 intellectually disabled children (age: 9-15), 24 virtual game addict university students (average age: 20) and 21 university students who play with VR games rarely or never (average age: 20). The task was colouring pictures using the colour palettes introduced below and answering some questions. The experiment was made in a dark room using a laptop computer, the monitor of which was calibrated by an Eye-One apparatus. Every observer has good colour vision, we tested them with Colourlite Colour Test (see a shorter version of this test:
http://www.colourvision.info/test_colour_vision_deficiency.htm). [214]

3.2.2.1. The test of memory colours

The observers had to paint the grey pictures using different palettes.

The tests were based on 3 tasks:

- "Extended colour palette" (Figure 3.11),

- “Given colour palette” (Figure 3.12), and
- “Answering questions” (Figure 3.13).

The observers first solved the “Extended colour palette” tasks. Here the observer could choose from 576 colours. The second task: “Given colour palette” was made one week later. There were 7 colour groups, every colour group consisted of 4 colours. The last task: “Answering questions” was made one week later after solving the earlier task. At the 3rd task the test software asks some questions, for example: What kind of colour is the sky? What kind of colour is the grass?

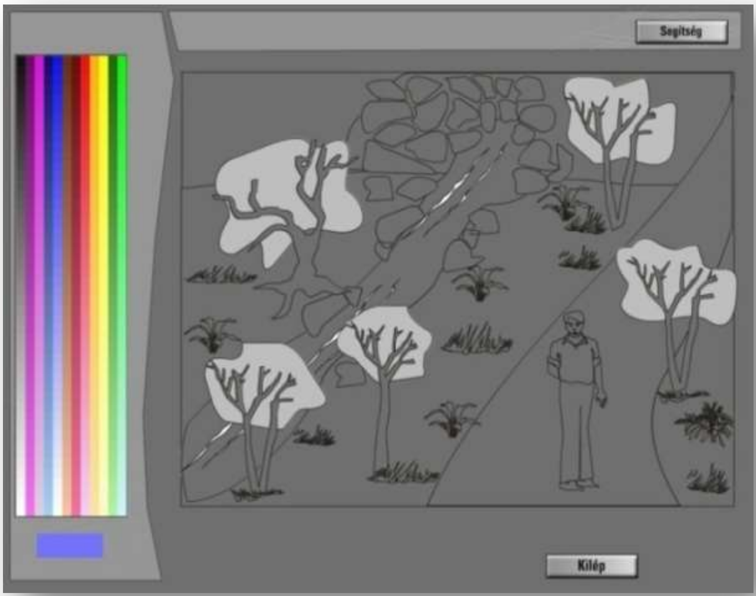


Figure 3.11. Extended colour palette task: colouring the foliage.

Figure 3.12. Given colour palette task: colouring the sun.

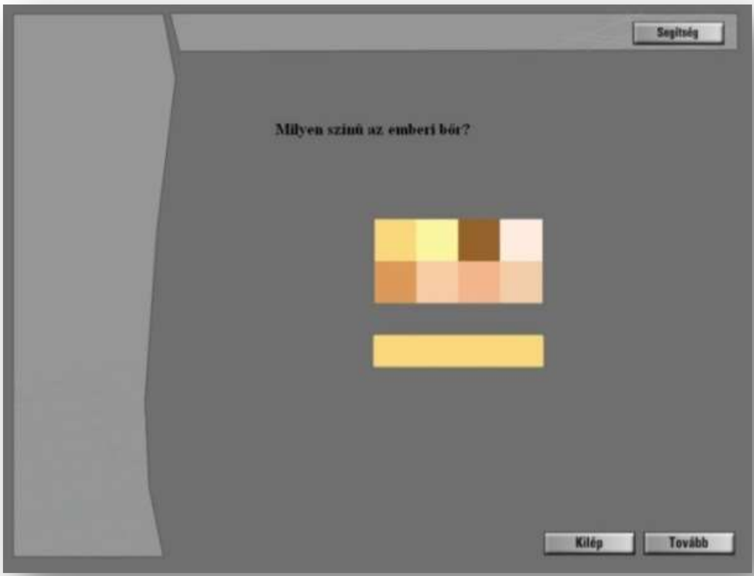


Figure 3.13. Answering questions task: What kind of colour has the Caucasian skin?

3.2.3 Results of the memory colour research

The test software saved the chosen colours at the colouring tasks and the answers of the observers. So, the software saved the $L*$, $a*$ and $b*$ values of the Caucasian face skin, foliage, sky, tree trunk, cloud, grass, sun, stone, sand, flower, water: stream, sea.

Table 3.8. Test results of the elementary school children

	Mean			Standard deviation		
form	$L*$	$a*$	$b*$	$L*$	$a*$	$b*$
sky	71.63	6.29	-35.08	9.63	8.91	14.89
tree trunk	44.66	10.69	24.85	5.74	6.44	2.79
cloud	69.75	7.81	-34.58	13.51	9.35	13.84
grass	76.85	-55.19	50.95	4.92	8.58	9.83
sand	83.59	-12.22	44.81	9.58	19.14	13.98
stone	51.02	0.05	0.83	13.67	4.20	5.89
foliage	70.85	-50.64	49.47	7.95	10.88	10.03
sun	94.90	-14.61	73.32	6.01	11.54	5.29
stream	67.95	-2.07	-24.75	9.27	15.50	20.51
Caucasian skin	86.07	4.17	31.90	5.92	11.50	13.24
sea	62.85	7.05	-37.54	7.37	10.92	14.01
flower	58.22	59.86	34.81	7.86	17.95	31.62

Tables 3.8 and 3.11 show the average CIELAB $L*$, $a*$, $b*$ and the standard deviation. Based on the data of the pilot test, there was significant difference in the memory colours especially of grass and Caucasian face skin.

Table 3.9. Test results of the intellectually disabled children

	Mean			Standard deviation		
form	*L**	*a**	*b**	*L**	*a**	*b**
sky	65.42	5.26	-36.10	13.44	12.93	14.35
tree trunk	50.19	10.45	27.35	10.96	9.61	4.86
cloud	59.94	3.87	-31.87	15.22	12.51	16.83
grass	72.58	-49.13	45.84	13.07	12.15	9.62
sand	84.84	-10.58	44.65	19.23	16.02	18.40
stone	57.19	0.84	8.65	24.90	10.00	13.82
foliage	67.32	-44.77	44.45	17.03	20.89	11.48
sun	94.00	-12.87	68.52	10.58	18.52	7.73
stream	61.48	3.74	-35.32	14.78	11.75	13.22
Caucasian skin	71.58	8.71	40.39	20.60	15.56	14.89
sea	68.13	-0.71	-29.84	14.25	11.33	29.78
flower	60.84	50.94	46.87	15.34	30.71	23.93

Table 3.10. Test results of the virtual game addict university students

	Mean			Standard deviation		
form	*L**	*a**	*b**	*L**	*a**	*b**
sky	69.73	9.13	-36.20	7.39	7.43	12.75
tree trunk	40.87	39.13	26.47	7.67	3.49	1.98
cloud	87.93	-1.40	-14.87	6.87	6.56	9.52
grass	19.09	-41.20	14.03	6.84	5.89	5.31
sand	89.27	-14.07	48.87	16.53	15.86	13.76
stone	23.77	-3.07	-1.00	18.25	0.86	0.24
foliage	47.87	-38.60	37.93	2.32	0.68	4.02
sun	99.90	-24.20	71.13	0.45	2.95	14.73
stream	62.53	7.67	-35.27	9.65	7.80	9.58
Caucasian skin	81.47	0.73	28.93	17.51	7.92	8.68
sea	57.93	12.00	-40.53	8.67	7.49	10.16
flower	45.27	67.07	54.47	14.20	22.65	18.01

Figure 3.14 and Figure 3.15 show the „bad" influence on memory colour of VR games. There is no significant difference between the average elementary school children, intellectually disabled children and university students who play with VR games rarely or never, but the virtual game addict university students' results differ from the other 3 groups significantly. The grass' memory colour of the virtual game addict university students is darker. This result agrees with the results we had by investigating the colours found in VR games, studied by game category: the colour of the grass of VR games was darker and browner, compared to the cartoon colours and the memory colours found in the literature [9], [34], [59].

Table 3.11. Test results of the university students who play with VR games rarely or never.

	Mean			Standard deviation		
form	*L**	*a**	*b**	*L**	*a**	*b**
sky	66.29	7.53	-34.71	9.07	11.40	11.75
tree trunk	41.35	16.82	31.18	6.31	0.81	7.80
cloud	80.71	0.53	-23.47	15.38	10.10	15.38
grass	64.65	-45.41	43.29	13.77	3.98	3.94
sand	93.00	-13.71	56.47	7.57	7.76	4.13
stone	64.59	-3.76	-0.53	13.37	0.98	0.57
foliage	68.00	-49.94	44.53	12.69	6.72	5.42
sun	99.82	-22.59	66.65	1.89	2.37	3.74
stream	65.18	-0.76	-26.24	9.05	7.29	2.85
Caucasian skin	94.88	-9.35	40.12	4.79	8.46	17.01
sea	66.94	1.94	-30.18	12.54	9.91	10.56
flower	49.12	72.59	38.12	7.29	5.79	30.35

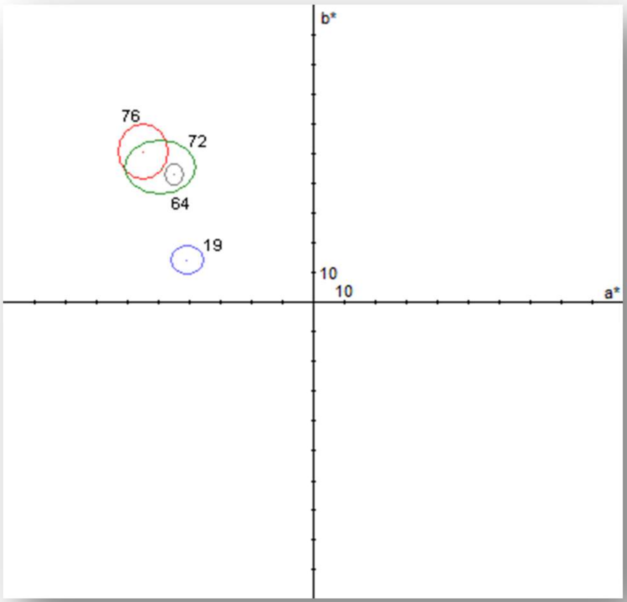


Figure 3.14. The result of memory colour of grass,
average elementary school children (red) $L^*=76$
children with intellectual disability (green) $L^*=72$,
game addict university students (blue) $L^*=19$,
university students who play with VR games rarely or never (grey) L*=64

Figure 3.15. Sample of the memory colour of grass,
upper row: Average elementary school children, children with intellectual disability
lower row: game addict university students, university students who play with VR games rarely or never.

The results of Caucasian face skin are different too. The memory colour of game addict students is more grey.

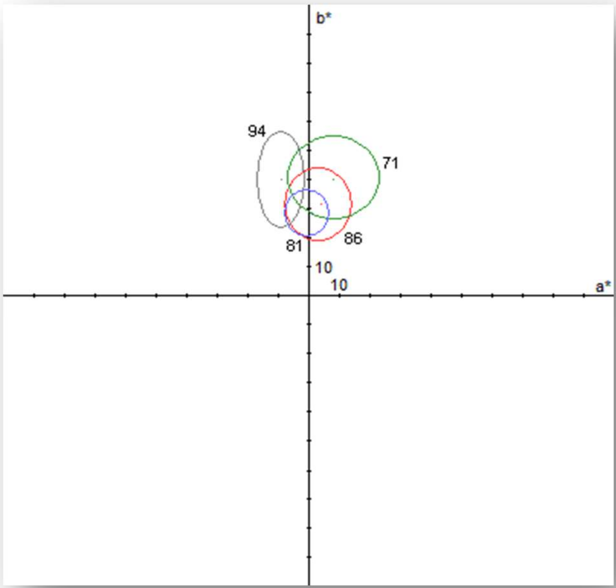


Figure 3.16. The result of memory Caucasian face skin,
average elementary school children (red) *L*=86*
children with intellectual disability (green) *L*=71*
game addict university students (blue) *L*=81*
university students who play with VR games rarely or never (grey) *L*=94*

Figure 3.19. Sample of the memory colour of Caucasian face skin,
upper row: Average elementary school children, children with intellectual disability
lower row: game addict university students, university students who play with VR games rarely or never.

The results show there was significant difference ($p<0.5$) in their memory colours between game addict university students and university students who play with VR games rarely or never. But there was no significant difference between the other three groups.

3.2.4 Conclusion of the memory colour research

Answering the questions in the introduction:

Are the memory colours of virtual game addict people influenced by VR games' colour, or not?

Yes, there was a definite difference found between the game addict observers and the other 3 groups.

When a child has some kind of intellectual disability or learning problems are his/her memory colours modified, compared to the average children, or not?

We found difference only in case of the Caucasian face skin colour.

In our earlier research – where we measured the colour use in VR games – it was realized [9], [34], that:

- in case of complexion colour: the colours are more yellowish than the memory colours.

- in case of grass colour: except for two categories (children and sport games) the colour of the grass was darker and browner, compared to the memory colours. So, the colour of the grass in the virtual games is false too.

- in case of sky colour: it was found in most cases, that more types of blue colours are used, in some cases they were far from the natural sky colour, they were more grayish.

The above-described analysis confirms hypothesis HI/2, therefore the **Subthesis I/2**. is the following: **The unrealistic colours of VR worlds influence our memory colours. The memory colour of the intellectually disabled students, non-gaming students, and VR addicts are different. [9], [35]** Unfortunately, we observed that the designers of the virtual games did not take care of using natural colours [9]. These colours are very far from the memory colours too.

We would like to call the attention of the designers of virtual games to use more natural shades of colours that is to say, colours that are near to the natural ones. Otherwise these colours will influence the memory colours of people, especially of children who play with VR games frequently.

3.3 Recommendations for the colour design of games

After the research, measurements and data analysis described in this chapter, the following recommendations can be made for the colour design of VR games:

1. **Determine the type of the planned game.**
2. **Determine the main target group of the game.**
3. **Analyse the colours of similar game categories. If you have a colorimeter, use it; if not, use an image editing tool for measuring colours.**
4. **Try to choose colours that are similar to those found in nature or use similar colours that you identified in the same game categories.**
5. **Use colours that are close to memory colours (see Table 2.1 in the Chapter 2).**
6. **You can do this by determining the difference between two colours based on the measurements. Use the 2.3 formula in Chapter 2. The colour difference ΔE^*_{ab} value should be between 2 and 3 according to the calculations! (See subchapter 2.2.1. in Chapter 2.)**
7. **Pay attention to the principles of colour harmony. (See subchapter 2.2.3. in Chapter 2.)**
8. **Test the game with the target users. Use a self-developed, game-specific questionnaire form for the test.**
9. **Modify the game based on the users' feedback.**

Chapter 4

Web accessibility investigations and health informatics

This chapter is based on my previous publications: four journal papers [4], [15], [16], [17], five publications in conference proceedings [37], [38], [40], [41], [54] and three book chapters [57], [58], [60].

In the first part of this chapter, I propose a method for testing websites for people with colour deficiencies. This research presents the colorimetric testing of websites of the Hungarian universities. In this testing, the main objective of the investigation was to find out how people with different colour deficiency types can perceive the information on those websites. Many IT engineers and web designers do not pay attention to the accessible aspect of websites. This accessibility implies that users who have any colour deficiency should be able to use the Internet the same way as people with no vision impairment.

In the second part of this chapter two investigations are elaborated. In the first one we developed a new validator software (XValid) based on the WCAG 2.0. We tested 18 countries' sites in 15 categories (approximately 500 sites) with XValid. Then a statistical analysis was performed based on the tests. We determined the most frequently occurring errors based on these statistics. In the second part of this research, the primary objective of it is to examine healthcare-related websites in 9 European countries in order to evaluate the status of their accessibility. Such a detailed statistical comparison has not yet been carried out in Europe, especially as this study offers a dual measurement system combining both the application of automated testing software and statistical analysis of user feedback. The study compares 48 websites from Eastern Europe with 51 sites from Western and Northern Europe. The research phase was performed in three steps, firstly by using AChecker, secondly by Nibbler and subsequently followed by user feedback questionnaires evaluated by a group of experts. The overall goal of this study is to determine the most common accessibility problems and to draw site owners' attention to shortcomings so that they can improve the quality of service of their healthcare-related sites in the future. The investigated European websites are grouped into Eastern and Western-Northern countries. We compared our results from different perspectives and ascertained that no significant differences can be established between the two groups predicated on their respective economic situations. Equally, no correlations were observed while comparing the sizes of webpages in Kbytes, the number of barriers and their Nibbler-Accessibility scores. Furthermore, there appears to be no correlation between the results of the software tests and the percentage of the elderly population in the respective country. Based on both research, I have determined a 11-promptly chart of WEB barrier-free recommendations. Moreover, I have developed an expert's questionnaire to test web pages.

This chapter also contains the used statistical methods and data analyses.

4.1 Colour-check on websites of the Hungarian universities

4.1.1 Introduction colour-check on websites of the Hungarian universities

Colour selection during design is very difficult, because the colour space is large and computer programmers are not colour designers [215]. Today's software developers are a specialist group; generally, they have no desire to attain a deep understanding of colour, but they have to produce applications (both offline and online) that are pleasant to look at and easy to work with. In summary:

- Colour selection is important for computer applications.
- Colour selection is difficult.
- Colour selection for interfaces concerns colour interaction more than individual colours.
- Computer application developers are not normally trained in colour choice or colour interactions, rather designing sites according to their own tastes and preconceptions.
- Computer application developers have become inured to garish colours.

The disorders in colour vision can be inherited and acquired. The cones' red and green colour specific paint cell's genes are linked to the X chromosome. Because of the gender-linked inheritance, this type of impairment is 20 times more prevalent in men. About 8% of Caucasian males and 0.4–0.5% of females are "red-green" colour-blind. Inherited blue-blindness (tritanopia) is much rarer – only about 0.05% of the population can be detected. Some colour vision disorders are not inherited, they are so called "acquired"; several ophthalmological diseases can result in colour perception disorders (e.g. retinal diseases, glaucoma, cataracts, etc.) [216].

It is quite common to see combinations of background and foreground colours that make pages virtually unreadable for colour-deficient users. Background, text, and graphics colours should be carefully chosen to allow for people with colour deficiency. Designing for colour deficient people is complicated. It's not a matter of green/red or yellow/blue combinations. The most important issue in designing for colour-deficient users is not to rely on colour alone to convey information and not to use colour as a primary means to impart information [217].

If we are unable to test our software with the help of colour-deficient people, we can at lease looked at in a greyscale setting to check whether or not all the information is visible. The following practices should be avoided if you want your website to be friendly to all visitors.

Errors marked in red: When filling out a form on a website, people often make a mistake. Typically, the form is checked when you submit it to see if all of the information appears to be valid. If you make a mistake, the form comes back with wording to the effect: 'Please fix your entries in the fields marked in red'. Just one problem... You've got a colour-deficient user seeing red because he/she can't see the red!

Black and white text provides good contrast and is easy for everyone to read. It is also typically pretty fine and frequently small as well. So, colour-deficient people can see the text well enough – light and dark contrast. But there isn't enough red to see the red - it is dark just like the black. If it were blue, they would see it right away, but red is the standardized colour for errors. If the red text is made bold, it becomes easier for anyone to pick up on and possible for colour-deficient people to see because now there is enough red present to pick it up.

Low Contrast Content: Good web design practice, in general, demands a reasonable amount of contrast between foreground and background. When you have a colour-deficient visitor, this becomes critical. In the best case, low contrast is difficult to read; in the worst case, it can't be read (Figure 4.1).

Any to very dark (or very light) colours are difficult to read for anyone. When that combination includes red, it is almost impossible for a colourblind person.
Any to very dark (or very light) colours are difficult to read for anyone. When that combination includes red, it is almost impossible for a colourblind person.

Figure 4.1. Bad example: low contrast difficult to read, or can't be read.

Displaying content with gradated colours, as is often done for graphs and some charts, is another example of the same thing. Unless each colour that signifies something is substantially different than the next, they will pretty well blend in for someone with colour-deficient vision. Why? After all, they are different colours! Well, gradated colours are going to contain elements of red and green. If someone is red/green colour-blind, these elements will not be visible, and everything looks like it is the slightest shade lighter or darker than the next item. Even then, a differentiation can be made - but only if the two are next to one another. Separate them and the difference is lost.

Certainly, these are not the only problems people with colour deficiency experience with websites. But these are the most common. Fortunately, more and more websites are working to be accessible to special needs users and their work is being supported by the recommended guidelines made by W3C [218].

Colour deficiency is often neglected, as most people do not consider colour deficiency as a serious problem. With up to 15% of the population being affected by one form or another of colour deficiency, everyone who has a website should be asking the question: Is it worthwhile to make sure my site is workable for such people?

The research question of this study is whether students with colour deficiencies can find the necessary information without information-loss. I formulate the hypothesis HII/1 that not every Hungarian higher education website is clearly visible, thus people with colour deficiency cannot access the information in the same "easy" way as the normal sighted.

Testing has been completed not only with several colour deficiency simulators on the internet, but also with Variantor's special glasses. The test method is based on the WCAG 2.0 standard [109]. Short description of this standard is written in subchapter 2.3. For this research, I used only the colour and visibility issues:

- Visibility and Colour-related principles and guidelines are Guideline 1.1, Guideline 1.3 and Guideline 1.4.
- Principle 1: Perceivable - Information and user interface components must be presentable to users in ways they can perceive.

This means that users must be able to perceive the information being presented (it can't be invisible to all of their senses).

- Guideline 1.1 Text Alternatives: Provide text alternatives for any non-text content so that it can be changed into other forms people need, such as large print, braille, speech, symbols or simpler language.
- Non-text Content: All non-text content that is presented to the user has a text alternative that serves the equivalent purpose, except for the situations listed below. (Level A)
- Guideline 1.3 Adaptable: Create content that can be presented in different ways (for example simpler layout) without losing information or structure.
- 1.3.3 Sensory Characteristics: Instructions provided for understanding and operating content do not rely solely on sensory characteristics of components such as shape, size, visual location, orientation, or sound. (Level A) Note: For requirements related to color, refer to Guideline 1.4.
- Guideline 1.4 Distinguishable: Make it easier for users to see and hear content including separating foreground from background.
- 1.4.1 Use of Color: Color is not used as the only visual means of conveying information, indicating an action, prompting a response, or distinguishing a visual element. (Level A) Note: This success criterion addresses color perception specifically. Other forms of perception are covered in Guideline 1.3 including programmatic access to color and other visual presentation coding.
- 1.4.4 Resize text: Except for captions and images of text, text can be resized without assistive technology up to 200 percent without loss of content or functionality. (Level AA)
- 1.4.6 Contrast (Enhanced): The visual presentation of text and images of text has a contrast ratio of at least 7:1, except for the following: (Level AAA)
- Large Text: Large-scale text and images of large-scale text have a contrast ratio of at least 4.5:1;
    - Incidental: Text or images of text that are part of an inactive user interface component, that are pure decoration, that are not visible to anyone, or that are part of a picture that contains significant other visual content, have no contrast requirement.
    - Logotypes: that is part of a logo or brand name has no minimum contrast requirement.

4.1.2 Method colour-check on websites of the Hungarian universities

All the 64 URLs of the Hungarian universities were collected. Four types of investigation were performed:

- automatic with AChecker [121],
- semi-automatic test: five different colour-blindness simulators were used, which are accessible on the Internet and where pictures can be uploaded [117-119] and also with a downloadable software, ColorOracle [120] with which we could test the pictures appearing on the screen on the developers' computer to find out how the users of different types of colour-blindness – deuteranopia, protanopia, tritanopia – see the colours.

- The fifth one was the SEE web-application [122],
- and human investigations with the Variantor special glasses [123] and answering to a questionnaire.

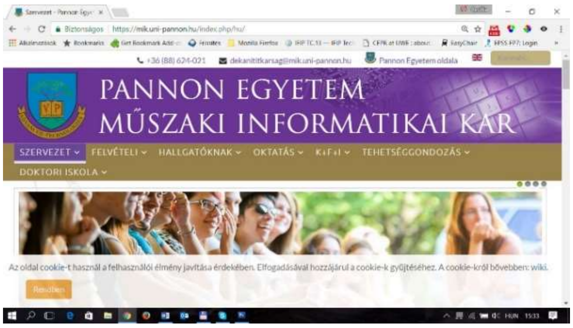


Figure 4.2. The original webpage of Faculty of Information Technology

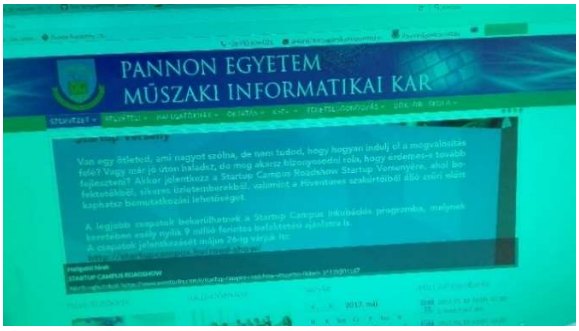


Figure 4.3. The webpage vision with Variantor glasses

4.1.3 Results of the checking the universities' websites

64 Hungarian university WEB-sites were tested. This section shows not only the statistical data but general observations as well. Table 1 contains the statistical analysis based on those guidelines which are in close connection with the visibility of WEB-sites.

The second column of Table 4.1 contains the "Levels of Conformance". All Success Criteria must be important access issues for people with disabilities that address problems beyond the usability problems that might be faced by all users. In other words, the access issue must cause a proportionately greater problem for people with disabilities than it causes for people without disabilities in order to be considered an accessibility issue (and covered under these accessibility guidelines). "Level A" is the minimum success criteria, where all WEB-pages must answer the requirements of accessibility. Unfortunately, as Table 4.1 shows, the 1.1.1 and 1.4.6 guidelines are mostly ignored by WEB-designers although these guidelines are very important from the point of visibility.

Table 4.1. Number of mistakes and problems by guidelines

Guidelines	Levels of conformance	Type of problems	summa number	largest number	average number
1.1.1 Non-text Content	(Level A)	Known	994	315	15.53
		Likely	21	6	0.33
		Potential	2416	237	37.75
1.3.3 Sensory Characteristics	(Level A)	Known	0	0	0
		Likely	0	0	0
		Potential	104	14	1.63
1.4.1 Use of Colour	(Level A)	Known	2	1	0.03
		Likely	0	0	0
		Potential	2871	160	44.86
1.4.4 Resize text	(Level AA)	Known	579	77	9.05
		Likely	0	0	0
		Potential	0	0	0
1.4.6 Contrast (Enhanced)	(Level AAA)	Known	2164	440	33.81
		Likely	0	0	0
		Potential	1466	144	22.91

The general experience is that there were very few WEB-pages which have an aesthetic value, moreover where colours harmonize with each other. Most WEB-pages are overcrowded, and it is very hard to use them. We do not want to criticize anybody therefore, the bad examples from our own University were chosen to demonstrate the typical mistakes.

The “Keresés” (search button written with light purple on a light brown background next to the English flag) in the upper right side of Figure 4.2 is invisible even for users with a proper vision.

Figure 4.4 demonstrates a design mistake: confusing colours. “Információk a 2016-/2017 tavaszi félévi államvizsgáról és diplomavédésről…” purple text in the right side of a black and white crest is very similar as blue colour of links. But it is not a link. This light purple is the same purple as the background of the main menu line and the colour of submenu text below it.

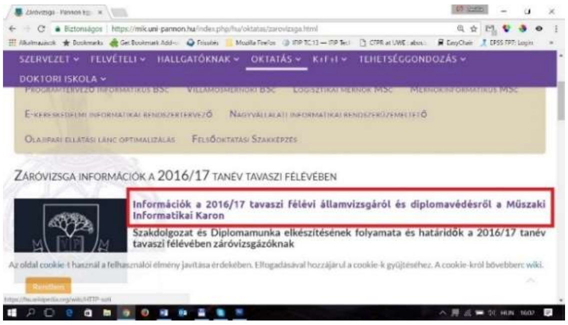


Figure 4.4. The original webpage of the information of the “final exam” site

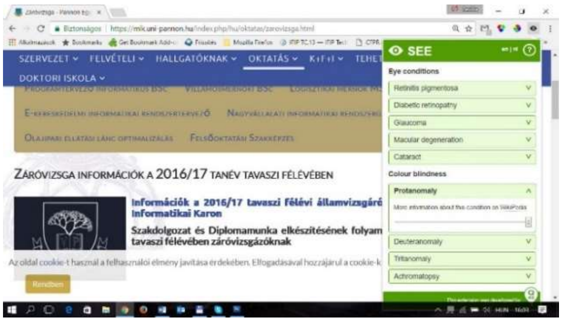


Figure 4.5. The webpage of the information of the “final exam” site as it is seen by a colour deficient user with protanomaly

Figure 4.5, Figure 4.6 and Figure 4.7 show how confusing is the that the “Információk a 2016/2017 tavaszi félévi államvizsgáról és diplomavédésről…” text looks like a link, although it is not a link.

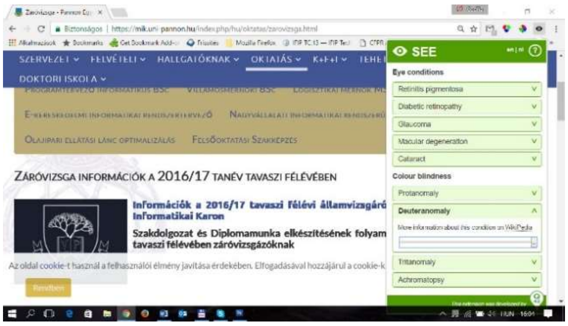


Figure 4.6. The webpage of the information of the “final exam” site as it is seen by a colour deficient user with deuteranomaly

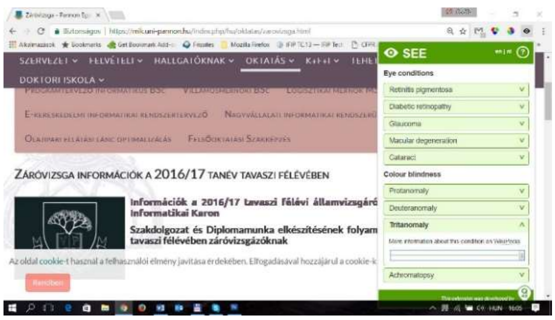


Figure 4.7. The webpage of the information of the “final exam” site as it is seen by a colour deficient user with tritanomaly

The “A dolgozat formai követelményei” text is a link, but it is coloured with a very pale blue. It is really hard to find that it is a link mainly with proper colour vision (Figure 4.8.) and in the case of tritanomaly (Figure 4.11).

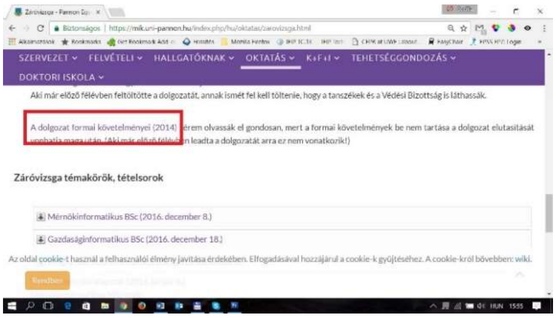


Figure 4.8. The original webpage of the information of the "formal requirements" site

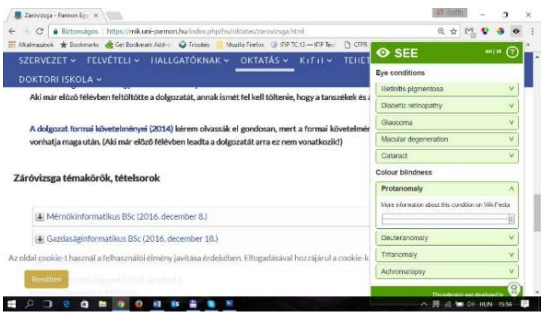


Figure 4.9. The webpage of the information of the "formal requirements" site as it is seen by a colour deficient user with protanomaly

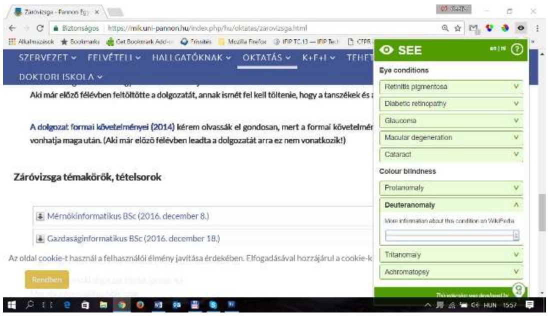


Figure 4.10. The webpage of the information of the "formal requirements" site as it is seen by a colour deficient user with deuteranomaly

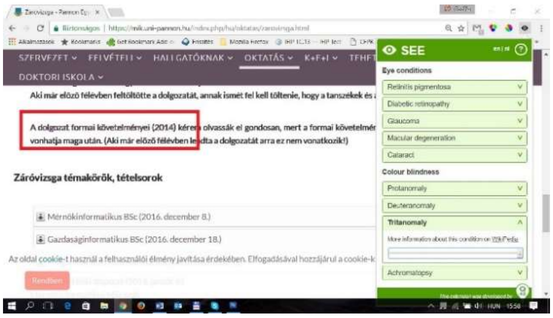


Figure 4.11. The webpage of the information of the "formal requirements" site as it is seen by a colour deficient user with tritanomaly

The last colour confusing example is the WEB page where a red distracting sentence and a pale blue e-mail address are written (Figure 4.12.). These pieces of information are difficult to notice in all cases (Figure 4.12.-Figure 4.15.) except the red sentence in Figure 4.14.

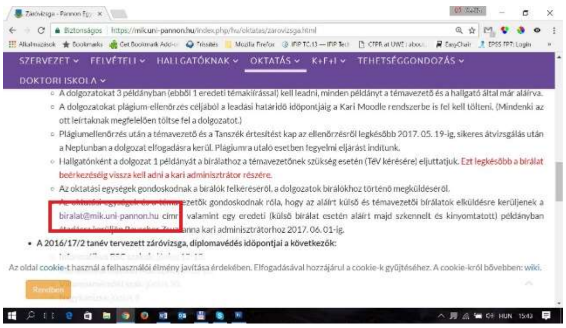


Figure 4.12. The original webpage of the information written with red and very pale blue

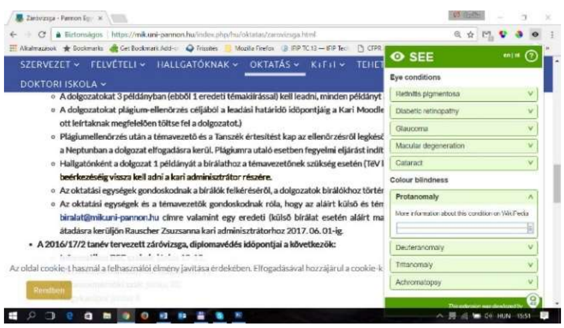


Figure 4.13. The webpage of the information written with red and very pale blue as it is seen by a colour deficient user with protanomaly

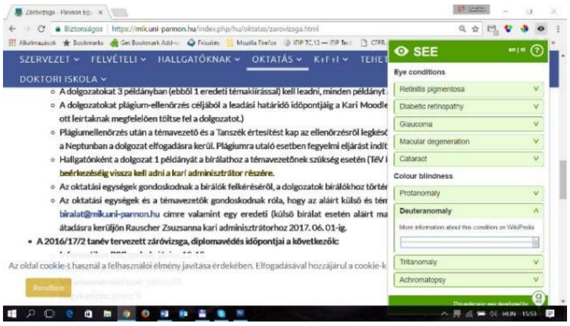


Figure 4.14. The webpage of the information written with red and very pale blue as it is seen by a colour deficient user with deuteranomaly

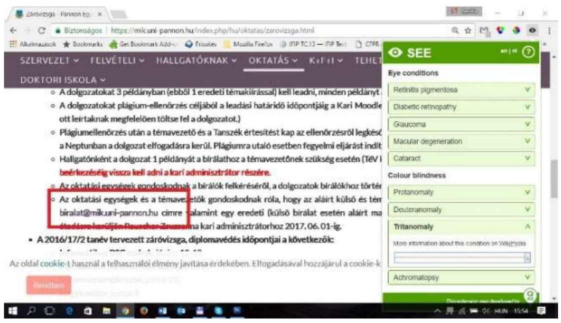


Figure 4.15. The webpage of the information written red and very pale pale blue as it is seen by a colour deficient user with tritanomaly

4.1.4 Conclusion of universities websites colour checking

The most important issue in designing for colour deficient users is not to rely on colour alone to convey information and not to use colour as a primary means to impart information [217].

We have not found any publications that consider the testing of colours of higher education home pages, lending credence to our view that IT engineers and web-sites' developers do not think about people with colour deficiency. As a result of our testing, we have reached the conclusion that, unfortunately, not every Hungarian higher education website is clearly visible, so students or future students with colour deficiency cannot get the information in the same "easy" way as the normal sighted. Therefore, hypothesis II/1 is acceptable.

Subthesis II/1. I proposed a method for the colour-correct design of WEB and VR games so that people with colour deficiencies will not lose information and gain accessibility. [15], [16], [40], [41], [57], [58]

My recommendation for web-designers:

- **Create websites where not only colours provide information. It means some patterns or huge contrast would be efficient for easy visibility of every chart, graph, button and link on the website.**
- **Test the website with different colour-blindness simulators.**
- **Test with real users. Involve people with colour deficiency.**

4.2 Web accessibility testing in 15 categories

In this research a new automatic testing tool, a validator (XValid) was developed. It is based on WCAG 2.0 [109].

4.2.1 Introduction web accessibility testing

The average web designers do not take the specific needs of the handicapped users into consideration, in spite of the fact that there are several guidelines available for a software product to be accessible with minimal requirements [219]. For example, the current amount of keyboard support in most common websites is far from being sufficient [220]. Therefore, a checklist and validator software XValid [37] was developed for testing home pages and e-learning materials from the viewpoint of universal design based on the guidelines of WCAG 2.0 [109].

Numerous validators are available as free services, for example W3C [218] quality assurance tools (W3C-QAT) [221], WebXACT [124]. Everyone has advantages and disadvantages. WebXACT is a free online service that lets you test single pages of web content for quality, accessibility, and privacy issues.

The W3C-QAT are almost universal tools for validating web standards, languages and CSS style-sheets, moreover they have specific tools – for specific needs, for example: RDF Validator [222] checks and visualises RDF documents. XML Schema Validator [223] is a form for checking a schema, which is accessible via the web. MUTAT [224] is a human-centred testing tool (framework). Almost all of these tools are web-based, are available both as downloadable sources, and as free services on the http://w3.org site.

Total Validator [225] is a free one-stop all-in-one validator comprising a HTML validator, an accessibility validator, a spelling validator, a broken links validator, and the ability to take screenshots with different browsers to see what web pages really look like. Since its release in 2005 Total Validator [225] has become extremely popular with web developers around the world. Unfortunately, in recent years it is not free anymore.

González et al. [226] proposed a remote testing approach, performing navigability testing in the user's home, employing special silent data gathering software agents, which are able to measure the user accuracy when performing navigation tasks.

The University of Illinois at Urbana/Champaign has developed a set of HTML best practices and accessibility management and visualisation tools to improve the design and verification of the functional accessibility of web sources [227].

Unfortunately, none of these is universal, which controls at the same time the accessibility and usability viewpoints of the following user groups: standard users, blind people, visually impaired people, deaf people, hearing impaired people, people with mobility and movement problems, people with cognitive problems and elderly people.

The XValid validator [37] is a human controlled testing tool for specific needs in light of accessibility and usability. Usability in the Web design has to cope with important elements like: Perceptibility, Understandability, Operability, Memorability Efficiency, Technical robustness because accessibility and usability have technical aspects as well as human interaction aspects [228]. The XValid validator software examines these elements too. At the time when it was developed, it was a unique tool and innovation.

The research question of this study is to find the most common errors based on WCAG 2.0 by using the XValid validator, ones that web designers seemingly repeat. The II/2.1 hypothesis is the following: Design recommendations could be formulated based on the most typical errors.

We tested 18 countries' sites in 15 categories: journals-, Web Shops-, Government-, commercial-, healthcare-, TV channels'-, timetable-, bank-, assistive technology-, free time-, museums'-, chat-, sport news- sites, e-learning and education sites, approximately

500 sites, with XValid We made a statistical analysis based on our test not only for Europe but outside Europe, in all 15 mentioned categories.

In our earlier research [37] we compared WebXACT and XValid softwares we found that while WebXACT detected some mistakes in 84.62% of all tested homepages, the XValid software found mistakes in 94.87 % the same homepages. XValid validator found 10.25% more mistakes than the WebXACT validator.

4.2.2 Developing the XVAlid software

XValid was developed with .Net framework 2.0. The code license of validation core is free, so anyone can build, modify or distribute it. It's a traditional desktop application, but because the validation core is a standalone library an online version is possible. XValid's main advantage is WCAG 2.0 conformity and the free availability.

The application is divided into two parts: the validation core and the graphical user interface.

Validation core is a standalone library, and it's capable to work without the GUI, so a later online version, or a non-Windows version is possible (although, the P/Invoked FreeImage may be a problem in this case). The application can analyse local files from the computer's file system, or a specific URL. In the first case the user clicks on the "Browse" button, and in the well-known Windows-way, selects a file. In the second case the user enters the exact URL into the textbox. After that the "Check" button can be pressed and some seconds later the report is appearing in the large white area. This report can be saved with the "Save Report" button. Figure 4.16 shows the validation process.

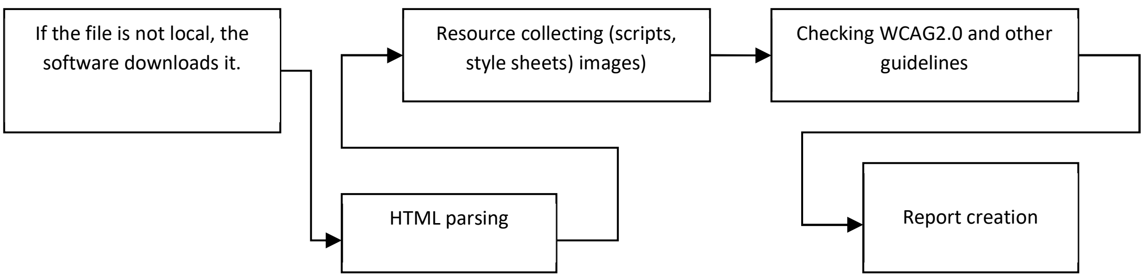


Figure 4.16. The validation processes.

The following guidelines of WCAG 2.0 are checked at this stage:

- 1.1.1: Alternative texts, Image maps (client- and server-side), Short descriptions, Long descriptions
- 1.3.1: Alternative texts
- 2.4.3: Titles
- 2.4.4: Alternative texts
- 3.1.1: Text direction and language
- 3.2.5: User requestable functions
- 4.1.1: Tag closings, Unique ids
- 4.1.2: Captions, Labels

The validation core tries to analyse every image for improper sizing, every script for unsafe functions (windows.open(), window.alert(), browser-specific codes…) and every style sheet for improper styles (although not capable to cover every problem).

The software uses the following 3rd party libraries:

- FreeImage.NET 3 - this is a free wrapper for the excellent FreeImage (which is used under the “FreeImage Public License - Version 1.0”), a free open-source graphics library.
- Self-modified version of MIL HTML Parser.
- The process (and application usage) is very simple from the user’s point of view. After starting the application, the following form is displayed (see Figure 4.17).

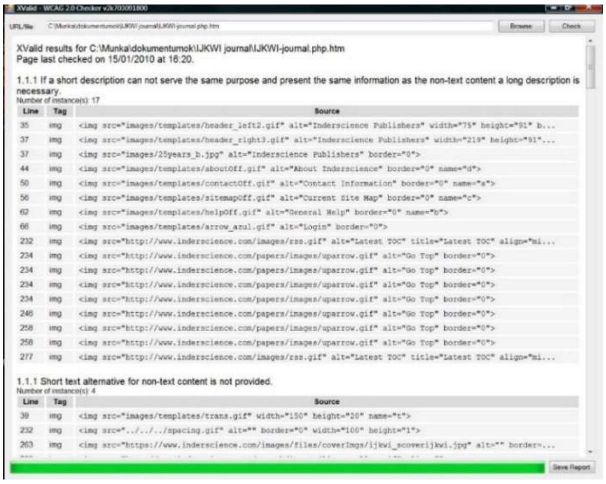


Figure 4.17. Testing the IJKWI Journal home page with XValid.

4.2.3 Web accessibility analysis

Approximately 500 URLs from 18 countries using XValid software were tested in 15 categories: journals-, web shops-, government-, commercial-, healthcare-, TV channels’-, time table-, bank-, assistive technology-, free time-, museums’-, chat-, sport news- sites, e-learning and education sites.

Table 4.2. The number of the tested websites by countries (country / number of tested sites)

Continent	Country	Number of tested sites
Europe	Austria	16
	France	37
	Germany	51
	Greece	14
	Hungary	50
	Italy	13
	Lithuania	24
	Norway	13
	Poland	48
	Slovakia	31
	Switzerland	18
	UK	25
outside of Europe	Arab language countries	17
	Israel	26
	Japan	21
	Peru	25
	USA	39
	Taiwan	40

340 European and 168 websites outside Europe, altogether 508 websites were tested by using XVlaid validator. Our XValid validator was the first which tests the WCAG 2.0 guidelines automatically. Tables 4.3 to 4.8 show the statistical analysis of this test.

Table 4.3. Percentage of websites with checkpoint errors of Guideline 1.1 of Principle 1

Guideline 1.1. Provide text alternatives for all non-text content	Country	Number of Websites not satisfying Guideline 1.1	Percen-tage	Number of errors
If a short description cannot serve the same purpose and present the same information as the non-text content a long description is necessary.	Hungarian	24	63.16	218
	EU Countries	219	77.65	2735
	Outside of the EU	95	66.43	1325
Short text alternative for non-text content is not provided.	Hungarian	33	86.84	3224
	EU Countries	244	86.52	12645
	Outside of the EU	116	81.12	5734
Short text alternative for non-text content is too long.	Hungarian	5	13.16	8
	EU Countries	74	26.24	183
	Outside of the EU	29	20.28	74
NOEMBED tag for EMBED tag is not provided.	Hungarian	15	39.47	89
	EU Countries	95	33.68	282
	Outside of the EU	39	27.27	84
Short/long description for non-text content is not provided. (Use elements' body.)	Hungarian	16	42.11	38
	EU Countries	94	33.34	178
	Outside of the EU	35	24.48	78
Short text alternative is part of image URL.	Hungarian	7	18.42	20
	EU Countries	62	21.99	210
	Outside of the EU	21	14.69	47
Short text alternative for non-text content is too short.	Hungarian	5	13.16	19
	EU Countries	86	30.50	491
	Outside of the EU	46	32.17	351
Alternative content for <iframe> element is not provided.	Hungarian	15	39.47	42
	EU Countries	72	25.53	158
	Outside of the EU	35	24.48	119
Client-side image map associated with this image, long description is necessary.	Hungarian	5	13.16	9
	EU Countries	44	15.60	66
	Outside of the EU	34	23.78	51
Redundant text link for some of the image maps' link is not provided.	Hungarian	5	13.16	8
	EU Countries	38	13.48	60
	Outside of the EU	24	16.78	37

The most serious problems are that the web designers do not take care of giving alternative short texts for all non-text elements (Table 4.3) or do not check the <title> tag whether it does identify the subject of the webpage correctly (Table 4.5) or do not use the html tags correctly, so the screen reader software does not know the primary natural language and reading direction (Table 4.6) and does not use the html tags correctly, so that the assistive technologies could parse the content accurately and do not have to correct them (Table 4.8).

We did not found errors in respect of the Guideline 1.2.

Table 4.4 shows the analyses of testing the Guideline 1.3. The percentage of errors is here in the first and second rows between 53–67 %.

We did not found errors in respect of Guidelines 1.4, 1.5, 2.1, 2.2, 2.3 and 2.5.

Table 4.4. Percentage of websites with checkpoint errors of Guideline 1.3 of Principle 1

Guideline 1.3. Ensure that information and structure can be separated from presentation.	**Country**	**Number of websites not satisfying Guideline 1.3**	**Percen-tage**	**Number of errors**
Use 'title' attribute to identify form controls when the <label> element cannot be used.	Hungarian	20	52.6	178
	EU Countries	173	61.35	1162
	Outside of the EU	77	53.85	482
Use <label> element to associate text label with form control.	Hungarian	21	55.26	179
	EU Countries	189	67.02	1255
	Outside of the EU	77	53.85	498
Advisory information provided with 'title' attribute is too long.	Hungarian	1	2.63	2
	EU Countries	6	2.13	8
	Outside of the EU	0	0	0
Advisory information provided with 'title' attribute is too short.	Hungarian	0	0	0
	EU Countries	3	1.06	4
	Outside of the EU	3	2.10	5

Table 4.5. Percentage of websites with checkpoint errors of Guideline 2.4 of Principle 2

Guideline 2.4 Provide mechanism to help users find content, orient themselves within it, and navigate through it	**Country**	**Number of websites not satisfying Guideline 2.4**	**Percen-tage**	**Number of errors**
Title tag correctly provided but it's important to check if it identifies the subject of the Web page.	Hungarian	38	100	38
	EU Countries	279	98.94	279
	Outside of the EU	142	99.30	142
Title tag is missing.	Hungarian	0	0	0
	EU Countries	1	0.35	1
	Outside of the EU	1	0.70	1
Title tag has too long value.	Hungarian	3	7.89	3
	EU Countries	54	19.15	84
	Outside of the EU	29	20.28	29
Short text alternative for non-text content is not provided.	Hungarian	2	5,26	6
	EU Countries	22	7.80	128
	Outside of the EU	22	15.38	102
Short text alternative for non-text content is too short.	Hungarian	2	5.26	6
	EU Countries	7	2.48	14
	Outside of the EU	3	2.10	10

The Table 4.5 analyses the correlation to the Guideline 2.4. Unfortunately, the first row contains 98-100 % errors. It seems that almost everybody disregards them therefore the results of our test show practically 100% error.

Table 4.6 shows the correlation to the Guideline 3.1. Here once again the first row is very critical, it contains 97-100 % errors. The Xvalid software found that none of the sites satisfy the instruction: <html> element having “dir” attribute.

Table 4.8 contains the analysis of the errors violating the Guideline 4.1. 81-90 % of the tested sites were incorrect (see first row) respectively 44-67 % (see 3rd and 4th row).

The analysis of the test of the Guideline 3.2 is seen in the Table 4.7. The results of the test show in the first row: 39–48 % errors.

Table 4.6. Percentage of websites with checkpoint errors of Guideline 3.1 of Principle 3

Guideline 3.1 Make text content readable and understandable	**Country**	**Number of websites not satisfying Guideline 3.1**	**Percentage**	**Number of errors**
The <html> element doesn’t have 'dir' attribute, which specifies the base direction of directionally neutral text. (The default direction is left-to-right.)	Hungarian	38	100	38
	EU Countries	274	97.16	275
	Outside of the EU	131	91.61	376
The <html> element doesn’t have 'lang' attribute, which specifies the base language of text content.	Hungarian	15	39.47	15
	EU Countries	200	70.92	206
	Outside of the EU	105	73.43	312

Table 4.7. Percentage of websites with checkpoint errors of Guideline 3.2 of Principle 3

Guideline 3.2 Make the placement and functionality of content predictable	**Country**	**Number of websites not satisfying Guideline 3.2**	**Percentage**	**Number of errors**
Script on page call window.open() function. Check that this is a user requestable function.	Hungarian	15	39.47	59
	EU Countries	134	47.52	600
	Outside of the EU	67	46.85	301
Script on page call alert() function. Check that this is a user requestable function.	Hungarian	11	28.95	38
	EU Countries	85	30.14	410
	Outside of the EU	33	23.08	254

The highest numbers of the errors are in the category of newspapers and TV channels in Hungary (Figure 4.18). The situation is the same in Europe, the highest number of the category are news, shop and entertainment (Figure 4.19). Outside Europe the highest number of the category is news, trip and bank (Figure 4.20).

Table 4.8. Percentage of websites with checkpoint errors of Guideline 4.1 of Principle 4

Guideline 4.1 Support compatibility with current and future user agents (including assistive technologies)	Country	Number of websites not satisfying Guideline 4.1	Percen-tage	Number of errors
This tag is not closed correctly. Assistive technologies may can't parse the content accurately.	Hungarian	31	81.58	5799
	EU Countries	253	89.72	28249
	Outside of the EU	123	86.01	9993
The 'id' attribute isn't unique.	Hungarian	8	21.05	70
	EU Countries	62	21.99	641
	Outside of the EU	31	21.68	666
Use 'title' attribute to identify form controls when the <label> element cannot be used.	Hungarian	17	44.74	174
	EU Countries	181	64.18	1219
	Outside of the EU	76	53.15	447
Use <label> element to associate text label with form control.	Hungarian	21	55.26	179
	EU Countries	189	67.02	1257
	Outside of the EU	74	51.75	509
Advisory information provided with 'title' attribute is too long.	Hungarian	1	2.63	2
	EU Countries	6	2.13	8
	Outside of the EU	0	0	0
Using <legend> element allows authors to assign a caption to a <fieldset> and improves accessibility.	Hungarian	0	0	0
	EU Countries	4	1.42	6
	Outside of the EU	2	1.40	14

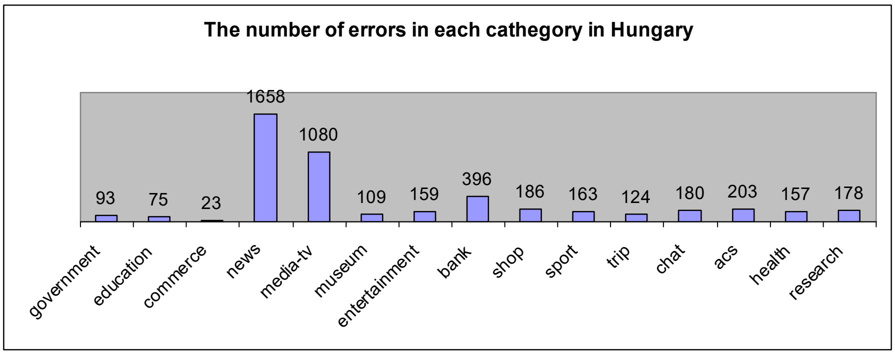


Figure 4.18. Number of errors in each category occurring on webpages in Hungary

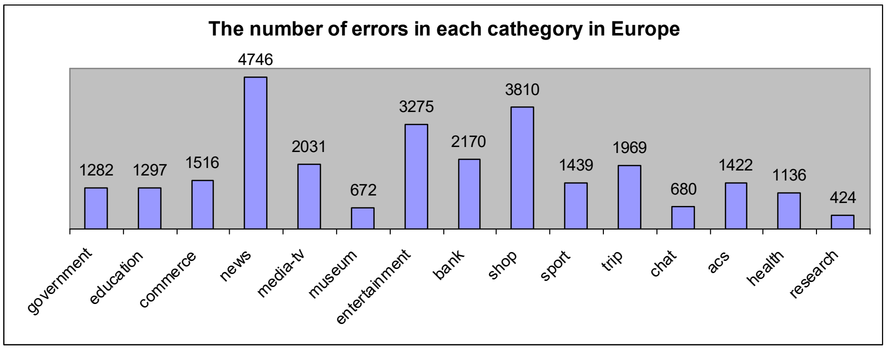


Figure 4.19. Number of errors in each category occurring on webpages in Europe

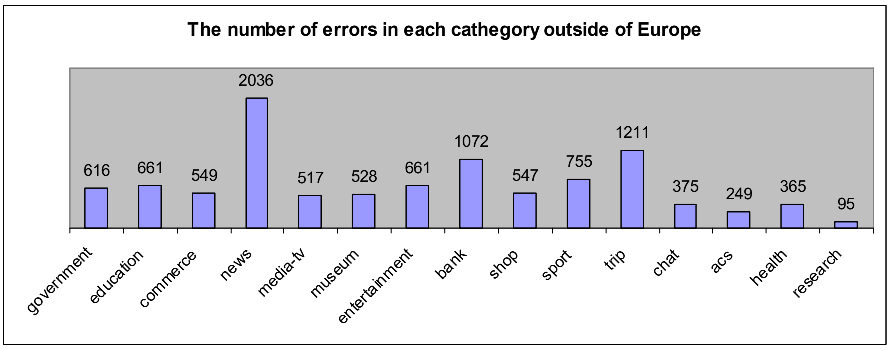


Figure 4.20. Number of errors in each category occurring on webpages outside of the EU

4.2.4 Conclusion of web accessibility testing in 15 categories

A new validator software called XValid for specific needs in light of design for all was developed. This validator was used for testing 18 countries' sites in 15 categories. (More than 500 individual tests were conducted.) Based on these tests statistical analysis was made for Hungarian, European and other web pages. According to the statistical analysis the II/2.1 hypothesis is accepted, and these statistics helped me to determine the most common errors. These have been considered when my recommendations were formulated. Based on this research work I provided a 10-point recommendation for the minimal requirement system that a web designer has to take into consideration so that more than 50 % of the WEB pages should be free of barriers.

i. **Provide alternative short texts for all non-text elements (e.g. images), and if one is not able to write a short description, then, use a long text.**
ii. **Use relative and positioning, rather than absolute.**
iii. **The content of the site should be accessible without using mouse (the appearance of the content) should not depend on JavaScript event handlers/modal windows.**
iv. **Use <label> tag defining the elements of the form and where it is not possible to use 'title' attribute.**
v. **The texts of references should to be understandable without their contexts.**
vi. **In the <html> tag identify the primary natural language using 'lang' attribute, and specify the base direction of directionally neutral text using 'dir' attribute.**
vii. **Provide summaries for tables using 'summary' attribute in <table> tag.**
viii. **Use separating characters between the links.**
ix. **Check the <title> tag whether it does identify the subject of the webpage correctly.**

x. The <html> tags should be closed correctly so that the assistive technologies can parse the content accurately and do not have to correct them.

Taking these recommendations into consideration and to follow them, would need not more money, neither would it take much more time in preparing the WEB page, just one has to be a little bit more attentive! I hope – that if the web designers will consider our 10-point recommendation – then we could contribute to make the web pages more barrier free.

4.3 Accessibility testing of European health-related websites

4.3.1 Introduction accessibility testing of European health-related websites

New solutions are needed for those elderly people who might not be able to leave their homes and for healthcare monitoring. Barrier-free Internet and software is an essential part of this process. Figure 4.21 shows elderly populations in the countries of the European Union (EU-28) in the period of 2004-2014.

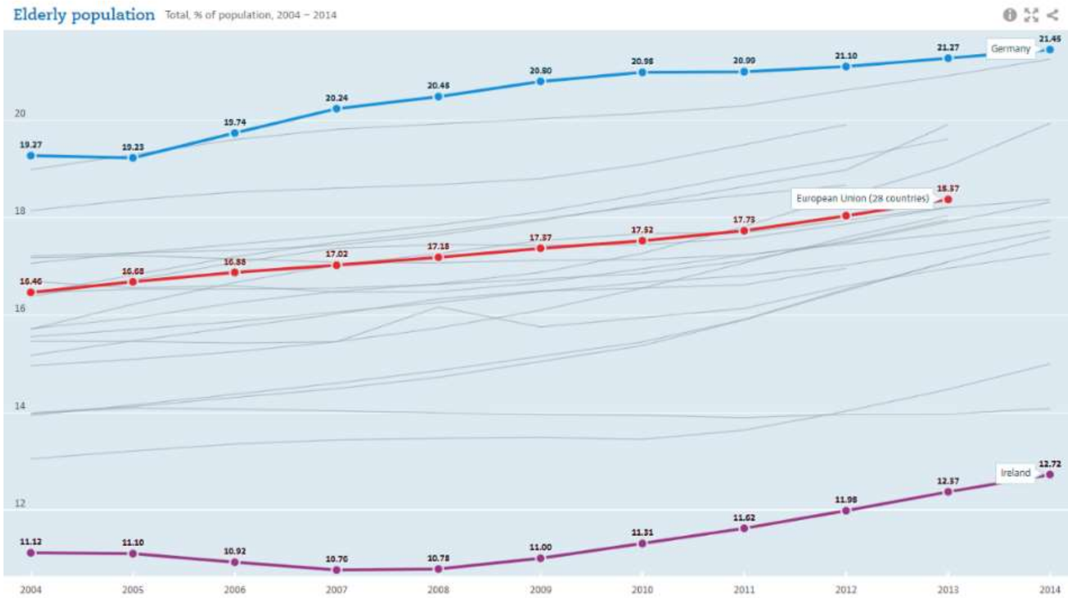


Figure 4.21. Elderly population in EU-28: Total percentage of population, 2004-2014 [229]

Table 4.9 shows the GDP, total population, region and percentage of the population in the countries included in this study from Central-Eastern-Europe (the so-called V4 countries), and from West-Europe (W-E) and North Europe (N-E). The size of the elderly population is increasing everywhere in Europe. Table 4.10. shows the GNI data and the region by each country in this study.

There has been extensive research dealing with Web accessibility, mainly in the domain of testing the accessibility of governmental websites [235-242] only to conclude that web sites are barely accessible and further research is required. Goodwin et al. [127] conducted the first global analysis of the Web accessibility of government websites of 192 United

Nation Member States almost 10 years ago. Among other things, they proved the following hypotheses:

- The wealthier a country is (GNI per capita), the fewer barriers will be present on its websites.
- A website with a WAI logo has better website accessibility scores.

Table 4.9. The GDP, the total population and elderly population numbers in the investigated countries.

Country	GDP 2017 US$ billion [230]	Total population (millions) in August 2018 [231]	Region	The elderly population % of total population in 2013 or 2014 [229]	The elderly population % of total population in 2017 [232]
Germany	3677.44	82.323	W-E	21.45 (2014)	22.06
Switzerland	678.89	8.555	W-E	17.6 (2013)	18.15
Sweden	538.04	9.994	N-E	19.91 (2013)	20.26
Austria	416.60	8.754	W-E	18.21 (2013)	19.26
Finland	251.88	5.545	N-E	19.94 (2014)	21.1
Poland	524.51	38.093	V4	15 (2014)	16.86
Czech Republic	215.73	10.626	V4	17.6 (2014)	18.98
Hungary	139.14	9.683	V4	17.72 (2014)	19.05
Slovakia	95.77	5.45	V4	no data available	15.43

Table 4.10. The GNI per capita in the investigated countries in 2017.

Country	GNI per capita, Atlas method (current US$) [233]	GNI per capita, PPP (current international $) [234]	Region
Germany	43,490.00	51,680.00	W-E
Switzerland	80,560.00	50,980.00	W-E
Sweden	52,590.00	65,610.00	N-E
Austria	45,450.00	52,500.00	W-E
Finland	44,580.00	45,400.00	N-E
Poland	12,730.00	27,970.00	V4
Czech Republic	18,160.00	34,450.00	V4
Hungary	12,870.00	26,960.00	V4
Slovakia	16,610.00	30,880.00	V4

Zheng [240] investigated 108 consumer health information websites in the USA. Although this research was performed in 2003 and based on WCAG1.0 [108], Zheng's research methodology used a taxonomy that classified the websites into 6 categories—E-commerce, corporate, government, portal, community and education. The result was that none of the websites was completely accessible to people with disabilities. Governmental, educational, health-related websites, nevertheless, exhibited better performance on web accessibility than other websites in other categories. They also established correlation between the accessibility and the popularity of a website.

Investigating web accessibility has become a frequently researched topic and a number of publications have appeared that address - among others - the accessibility of such institutions as universities. A group of Brazilian researchers [241] for instance set out to investigate Brazilian federal universities to see if they complied with e-government standards. Unfortunately, their results confirmed that most federal university websites do not follow important accessibility standards. Some of the reasons behind the findings include IT teams that are unable to cope with staff shortage, high demand, tight deadlines, and the lack of specific development methods. Our own research [16] looks at the websites of Hungarian universities to discover potential accessibility issues of students who have some colour deficiency problems. Our results make it clear that, unfortunately, not every website is clearly visible; therefore students with colour deficiencies cannot acquire information the same way as healthy ones. Our recommendation for web-designers here is to create websites that do not only feature colour visual cues, i.e. the implementation of various patterns and huge visual contrasts would be more efficient to promote visibility in texts, buttons and links. In general website designers do not tend to develop different versions of the same site for each disability type, in fact, it is unlikely that further features are added for the comfort of different disability groups. [3], [17], [37], [55]

The priorities of the European Commission include the simplification of modern digital contract rules, the promotion of access to digital content, and the enhancement of online sales [91], [243]. The EC wishes to support digital market strategies in the member countries and introduce new e-commercial regulations in order to make buying and selling goods inside the EU easier [244].

In this chapter, I present the results of testing and evaluating almost 100 healthcare-related websites from 9 European countries. Based on the results, I will review my earlier recommendations outlined in an earlier paper [17] to see whether they still hold. The following sections will set out the context of the research, its implementation and results and, finally, looks at the proposed hypotheses. Section 4.3.3 details the research methodology and hypotheses. The applied statistical method is written in subchapter 2.4 “Methodological contributions of the thesis”. Section 4.3.4 discusses the results, and sections 4.3.5 and 4.3.6 present the discussion and main conclusions of the research.

4.3.2 Materials and methods

The present study highlights the most acute accessibility problems of the examined healthcare-related websites. The investigation includes healthcare-related sites from 9 European countries; 48 from Eastern Europe (the so called V4 countries), and 51 sites from Western and Northern Europe (N-W-EU). Table 4.11 shows the number of tested websites in the investigated European countries.

Table 4.11. Number of the tested websites.

Country	Number of the tested website	Region
Germany (GER)	9	N-W-EU
Switzerland (SWI)	16	N-W-EU
Sweden (SWE)	8	N-W-EU
Austria (AU)	8	N-W-EU
Finland (FIN)	10	N-W-EU
Poland (PO)	8	V4 countries
Czech Republic (CZR)	8	V4 countries
Hungary (HU)	19	V4 countries
Slovakia (SLO)	13	V4 countries

The V4 countries were examined together because, on the one hand, they form one region, on the other hand, economically, historically and from an educational point of view they are very similar. Salaries in the V4 countries amount to one third or one fifth of that in the western part of Europe, while the prices of basic foods and daily necessities do not differ between significantly.

As the accessibility properties of the web pages can be considered random qualities, the comparisons require statistical methods. This research uses both quantitative and qualitative research method. The measurement of web accessibility is addressed in this section.

The websites that fall within the scope of interest of the present investigation were chosen based on Google search results, concentrating on top finds. For automatic testing AChecker [121] and Nibbler [126] were used. To improve the depth of the present research we extended our automated tests by interviewing users in the framework of a questionnaire. I involved experts with considerable experience gained in the area of digital accessibility to compile a questionnaire (See: Table 4.12) and elicit useful feedback from users with regard to their accessibility issues. The experts involved in the present investigation include MSc IT engineer university students specialized at Software Ergonomics, Human Computer Interaction, User interface Design and Web Accessibility.

Table 4.12. Questionnaire of the experts' test

Questions	Remarks
1. Does the website have a blind version? (yes/no)	Developing a blind version site is not a good solution.
2. Each link can be determined based on the link text alone.	E.g. "click here" or "here" links are not understandable.
2.1 Can linked texts be followed?	If the earlier answer is "yes", please write the text of the link here.
3. Is information lost by a user with colour deficiency?	Check it with the Google SEE web-application.
3.1 Protanomaly 3.2 Deuteranomaly 3.3 Tritanomaly 3.4 Achromatopsy	If you answered "yes" to the previous question, please indicate here which colour information was lost!
4. Is there CAPTCHA on the website? (yes/no)	For this question, look at the whole web page, not just the main page!
4.1 If CAPTCHA is available, can it be heard? (yes / no)	-
5. Is every part accessible by using the keyboard? (yes/no) 5.1 Inaccessible features	Use TAB to scroll through all menu items; can you enter all submenu points; all functions are available on the main page? If your answer was "no" to the previous question, type here what was unavailable on the keyboard!
6. Is there an English-language website? (yes / no)	-
6.1 Is the information same on the opening page in English and in the national language? (yes / no)	-
7. Is the website responsive? (Yes No)	
8. Is WAI logo indicated on the site? (Yes No)	-

As mentioned, the testing phase started with AChecker, followed by Nibbler and ended with the questionnaires (Table 4.11) including the use of the SEE web-application [122] (question 3 in the Table 4.11). The SEE web-application proved to be the best and easiest test-software from the point of view of handling because the user only needs to set a colour deficiency type with a slider and does not have to upload a picture to a web page as in the case of other testers. The test phase is concluded with the use of Variantor special glasses [123].

All these tests were performed in the time period of June-July 2018. The most frequently visited and most popular sites were chosen by Goggle statistics for the test upon searching for “healthcare”, “assistive technology”, “health related”, etc. keywords. Focus of interest where websites that contained health-related information or blogs about health topics or webshops for medicaments or assistive technologies. Moreover, we consulted native speakers in the respective countries and asked them to send us the URLs of the most popular websites in their areas of interest.

4.3.3 Hypotheses and research questions

This chapter presents the Research Questions (Q) and Hypotheses (H) of the chapter’s topic based on related questions. They are grouped based on closely related topics. The scenario is based on the order of first asking a question, then the statistical hypothesis is formulated together with its alternative (H).

4.3.3.1 Testing by Nibbler

Q II/3.1: Can we ascertain significant differences between the groups of V4 countries and N-W-EU countries performing the evaluation by the data of Nibbler test investigating the different aspects separately?

H II/3.1: Are the expectations of the scores of the V4 countries and N-W-EU-countries regarding the aspects separately equal versus the alternative hypothesis that they are different?

Q II/3.2: How large are the correlation coefficients and determination coefficients between the points of the different aspects? Is there any relation between the different aspects? Can the scores of the different aspects be considered statistically independent or higher technology results higher accessibility?

H II/3.2: Is the correlation coefficient between the different aspects equal to zero or it is not? What about the one-sided alternative hypothesis?

4.3.3.2 Testing by AChecker

Q II/3.3: Can we see significant differences in average error numbers in the N-W-EU and V4 countries grouping the questions by their types (using the AChecker automated tool)? What is the situation if we focus on the questions separately and what about the most affected principles?

H II/3.3: There are no differences between the V4 and N-W-EU countries concerning the average error numbers, versus there is difference between the error numbers. The expectations of the error numbers are the same statistically in the case of the most frequently effected principles comparing V4 and N-W-EU countries versus the non-equality.

Q II/3.4: Are the conformance levels (A, AA, AAA) the same in the N-W-EU and V4 countries based on the error numbers (by using the AChecker automated tool)?

H II/3.4: The average error numbers are equal comparing V4 and N-W-EU countries in case of each conformance level versus they are different.

Q II/3.5: Which are the most frequently violated principles based on the error numbers of AChecker results and how much are the extreme values?

H II/3.5: Most error numbers originate when web developers violate the first principle.

4.3.3.3 Comparison

Q II/3.6: Is there any relation between the scores of the separate websites given by Nibbler tests and AChecker tests or are they independent? What about the average scores of websites belonging to the same countries? How much are the correlation coefficients?

H II/3.6: The correlation between the scores by Nibbler test and the error numbers provided by AChecker is zero, versus it differs from zero, investigating websites separately and grouping them by countries.

4.3.3.4 Human aspects

Q II/3.7: Should users who have any colour-deficiency be able to use the investigated websites the same way as people with no vision impairment (by using as test tool the SEE web-application and the Variantor special glasses)?

H II/3.7: Users who have any colour-deficiency are able to use the investigated websites the same way as people with no vision impairment (by using as test tool the SEE web-application and the Variantor special glasses).

Q II/3.8: Is there any difference between the N-W-EU and V4 countries based on the experts' test?

H II/3.8: There is no significant difference between the N-W-EU and V4 countries based on the evaluation of the experts' questionnaire.

4.3.3.5 External and internal characteristics and web accessibility

Previous research upholds [127] that the wealthier a country is (GNI per capita), the fewer barriers will hinder the use of websites. Moreover, website with a WAI logo have better accessibility scores. Furthermore, there is a correlation between the size of webpages and the number of barriers detected. Well, we challenged these findings only to prove the opposite, i.e. neither of the above statements hold true for health-related webpages.

4.3.3.5.1. Correlation between the sizes of the webpage and barriers

Q II/3.9: Is there any correlation between the sizes in Kbytes of the website and the number of known problems by AChecker and the Nibbler Accessibility scores? How large are the correlation coefficients?

H II/3.9: The correlation coefficients between the sizes in Kbytes of websites and the numbers of known problems by the AChecker/ the Nibbler Accessibility scores are zero. The alternative hypothesis is that the correlations differ from zero, that is the sizes and the accessibility are dependent.

4.3.3.5.2. Correlation between the economic aspects and barriers

Q II/3.10: Are there any links between the GNI per capita of a country and the known problems by AChecker /the Nibbler Accessibility score of the web pages? How large are the correlation coefficients?

H II/3.10: The economic character of a country does not effect on the Web-accessibility versus the alternative hypothesis the wealthier a country is (GNI per capita), the fewer barriers will be found on its websites.

4.3.3.5.3. Correlation between the number of elderly citizens and barriers

Q II/3.11: Are there any correlation between the size of elderly population and the known problems by AChecker and the Nibbler Accessibility scores? How large are the correlation coefficients? Does higher ratio of the elderly population produce accessible websites?

H II/3.11: Ratio of the elderly population is independent of the number of known problems versus these quantities are dependent.

4.3.4 Results of accessibility testing of European health-related websites

4.3.4.1 Results based on the Nibbler tests

Answer to Q II/3.1: Grouping the questions by properties we cannot find significant differences between the results of the groups in case of V4 and N-W-EU countries. If we compare the V4 and N-W-EU countries by the groups of questions, there are significant differences between the expectations of the question-groups except the areas of Experiences and Marketing.

Table 4.13. Average values and dispersions in case of groups of countries and groups of questions

	V4		N-W-EU		TOTAL	
	average	**dispersion**	**average**	**dispersion**	**average**	**Dispersion**
Accessibility	8.845	1.823	8.923	1.933	8.886	1.88
Experiences	7.125	3.734	7.329	3.536	7.232	3.631
Marketing	7.369	3.5	7.222	3.467	7.292	3.482
Technology	7.995	2.982	8.09	3.136	8.045	2.903

Table 4.13 shows that the largest averages belong to accessibility and the smallest ones to the experiences in almost all cases.

The equality test in each question group was performed. The p-values are displayed in Table 4.14.

Table 4.14. The p-values of the tests

	V4: N-W-EU
Accessibility	0.646
Experiences	0.357
Marketing	0.467
Technology	0.649

Table 4.14. confirms that the expectations of the V4 countries can be considered the same as the expectations of the N-W-EU countries in all groups of questions. If we make the pairs of question-groups we have $\binom{4}{2} = 6$ pairs. Performing the tests of equalities of the expectations for all pairs we have the following results (Table 4.15).

Table 4.15. The p-values belonging to the tests of equalities

	V4	N-W-EU	TOTAL
Accessibility-Experiences	1.18E-16	2.48E-16	2.09E-31
Accessibility-Marketing	2.15E-14	1.58E-19	2.63E-32
Accessibility-Technology	1.45E-05	6.67E-06	3.91E-10
Experiences-Marketing	0.269032	0.59758	0.689924
Experiences -Technology	0.000118	0.000187	8.07E-08
Marketing- Technology	0.003382	1.10E-05	2.04E-07

Table 4.15 shows that there is no significant difference between Experiences and Marketing scores, but all other pairs present significant differences. The statement is true for the V4 countries, for the N-W-EU countries and for all countries too. The best performing area is Accessibility, it is followed by Technology and the last areas are Marketing and Technology.

Answer to Q II/3.2: Investigating the correlations between the areas we found the following correlation coefficients (Table 4.16). The scores of the different groups of questions are not independent except Marketing and Technology. Higher scores in one area imply higher scores in another one. Marketing and Technology are independent in the case of V4 countries but considering N-W-EU countries or all data the statement does not hold. Testing the independence of the areas, i.e. the scores belonging to the separate aspects, the results are summarized in Table 4.18.

Table 4.16. Correlations between the results of groups of questions in case of V4, N-W-EU countries and in all countries

	V4	N-W-EU	TOTAL
Accessibility-Experiences	0.602	0.496	0.538
Accessibility-Marketing	0.273	0.25	0.254
Accessibility-Technology	0.564	0.448	0.508
Experiences-Marketing	0.721	0.795	0.756
Experiences -Technology	0.559	0.709	0.641
Marketing- Technology	0.171	0.541	0.37

Table 4.16 presents usually medium positive correlations. The relation is stochastic, the scores change together in the same direction on average, largest Accessibility implies largest Experience and Technology. In case of Accessibility and Marketing, Technology and Marketing correlations are rather small.

The determination coefficients are shown in Table 4.17. Table 4.17 demonstrates that determination of one area by another is slight, usually is under 50% in most cases.

Table 4.17. Determination coefficients in the case V4, N-W-EU and all investigated countries

	V4	N-W-EU	TOTAL
Accessibility-Experiences	0.363	0.246	0.289
Accessibility-Marketing	0.075	0.062	0.065
Accessibility-Technology	0.318	0.201	0.258
Experiences-Marketing	0.52	0.632	0.571
Experiences-Technology	0.313	0.502	0.411
Marketing-Technology	0.029	0.293	0.137

Table 4.18. P-values of the test of independence in the case of one one-sided and two-sided alternative hypothesis

	Two sided alternative hypothesis			One sided alternative hypothesis		
	V4	N-W-EU	TOTAL	V4	N-W-EU	TOTAL
Accessibility-Experiences	0	0	0	0	0	0
Accessibility-Marketing	0.063	0.074	0.011	0.033	0.037	0.006
Accessibility-Technology	0	0.001	0	0	0.0005	0
Experiences-Marketing	0	0	0	0	0	0
Experiences -Technology	0	0	0	0	0	0
Marketing- Technology	0.249	0	0	0.125	0	0

Decisions are presented in Table 4.19.

In the columns concerning the two-sided alternative hypothesis we can see that independence is acceptable in the case of Accessibility and Marketing if we investigate V4 countries or N-W-EU countries. But the p-values 0,063 and 0,074 are close to the standard 0.05 value. The number of webpages included in the study is 48 and 51 respectively. If we investigate all of them together, the total number is 99, the dependence is demonstrable on the level of significance 0,011. The independence of Marketing and Technology is acceptable in the case of one-sided and two-sided tests on the level of significance 0,249 and 0.125, respectively, in the case of V4 countries.

Table 4.19. Decisions about the independence of areas (D=dependent, I=independent)

	Two-sided alternative hypothesis			One-sided alternative hypothesis		
	V4	N-W-EU	TOTAL	V4	N-W-EU	TOTAL
Accessibility-Experiences	D	D	D	D	D	D
Accessibility-Marketing	I	I	D	D	D	D
Accessibility-Technology	D	D	D	D	D	D
Experiences-Marketing	D	D	D	D	D	D
Experiences -Technology	D	D	D	D	D	D
Marketing- Technology	I	D	D	I	D	D

4.3.4.2 Results based on the AChecker tests

Answer to Q II/3.3: There are no significant differences between V4 and N-W-EU countries in the expected number of known and likely errors but there is in the number of potential errors. The total number of the errors is significantly higher in V4 countries than in N-W-EU countries, but the difference is due to the potential errors. If we compare the V4 and N-W-EU countries grouping the test questions based on type, we get the following average values (Table 4.20). In the case of both V4 and N-W-EU countries the most frequent known errors are „Non-text content", „Contrast (Enhanced)" and „Resize text". This emphasizes the similarity between the properties of the V4 and N-W-EU countries. The average values can be seen in Table 4.23.

If we compare the V4 countries and N-W-EU countries by grouping the errors by types, i.e. by the known, likely and potential error numbers, we get the results contained in Table 4.21.

Table 4.20. The average values in the case of different error types

	V4	N-W-EU	TOTAL
Known	45.426	47.686	46.602
Likely	0.894	1.902	1.418
Potential	710.681	487.941	594.765
Total	757.1	537.529	642.785

Table 4.21. The significance levels testing the equality of the numbers of errors in the web pages of V4 and N-W-EU countries

Error type	Known	Likely	Potential	Total	
				Two sided	One sided
P-value	0,886	0,297	0,005	0,082	0,041

The data found Table 4.21 confirm that in the case of known and likely errors there are no significant differences between the groups of V4 and N-W-EU countries, but in the case of potential errors there is. If we consider all types of errors, we can state that the number of the errors of websites in V4 countries is significantly higher than that of N-W-EU countries provided we use one-sided tests (p-value is under the level 0.05). The difference, however, is not significant if we test non-equality by two-sided test. The last result can be explained by the large dispersions values.

Investigating the number of errors in the websites of V4 and N-W-EU countries, we can state that there are usually no significant differences between the V4 and the N-W-EU countries even from the perspective of questions. Performing the Welch test for every question separately (183 tests) we found significant differences in 9 cases, these are presented in Table 4.22. It should be highlighted that all errors except from 3.3.2 are potential errors and only one known error can be found among them.

Table 4.22. Number of guideline's subsections (error type) in case of significant differences between the V4 and N-W-EU countries

Number of error type	Interpretation of the Success Criterion	Error type	Sign. level
1.1.1.	Non-text content (Level A)	potential	0.02
1.3.1	Info and relationships (Level A)	potential	0.035
1.4.1.	Use of colour (Level A)	potential	0.028
1.4.5.	Images of text (Level AA)	potential	0.019
2.4.3.	Focus order (Level A)	potential	0.016
2.4.4.	Link Purpose (In Context) (Level A)	potential	0.030
3.1.2	Language of parts (Level AA)	potential	0.001
3.2.1	On Focus (Level A)	potential	0.014
3.3.2.	Labels or Instructions (Level A)	known	0.015

Table 4.23. The most frequent known errors in the case of different groups of countries and in the case if all countries

Type of known error	V4	N-W-EU	Total	Sign. level
1.1.1. Non-text content	11.208	29.686	20.727	0.1389
1.4.4 Resized text	10.437	5.392	7.838	0.258
1.4.6 Contrast (Enhanced)	10.563	3.255	6.79	0.209

Although the maximal number of the average error is higher in the group of N-W-EU countries than in the group of V4 countries, the opposite is true for the second and the third values in the rank. Moreover, the differences are not significant, as it can be seen from the values in the last column, a consequence of the large values in the standard deviations.

Answer to Q II/3.4: We cannot ascertain significant differences between the V4 countries and the N-W-EU countries by the level of conformances of known errors. Grouping the questions by level of conformance (A, AA and AAA) we performed the equality test for the expectations of the number of errors in the case of known errors. The average values of the groups and the p-values are presented in Table 4.24.

Table 4.24. The average values of the groups in case of known errors

Success criteria (level of conformance)	V4	N-W-EU	TOTAL	P-value
A	1.094	1.60866	1.359	0.350
AA	0.859	0.26	0.687	0.313
AAA	0.463	0.150	0.301	0.271

Table 4.25. The numbers of errors violating the different error types

	V4			N-W-EU			COMP.	TOTAL	
Level	**Mean**	**Disp**	**Max**	**Mean**	**Disp**	**Max**	**p-value**	**mean**	**Disp**
A	26.25	34.54	213	38.608	86.81	371	0.35	32.616	66.75
AA	11.167	24.82	155	6.843	12.532	68	0.82	8.939	19.501
AAA	10.646	42.677	275	3.451	12.415	63	0.266	6.939	31.068

In Table 4.24 it can be seen that in the case of the level A group V4 has better values, but in the case of level AA and AAA the N-W-EU group has fewer errors. Performing the test of equality, we do not see significant differences between the groups of countries. The number of errors violating success criteria (level of conformance) A, AA and AAA can be found in Table 4.25. We can conclude that there is no significant difference between the V4 countries and the N-W-EU countries. The average number of N-W-EU is larger in the case of error type A. The reverse is true in the case of error types AA and AAA. The maximal values are large as compared to the average, which causes large dispersions.

Answer to Q II/3.5: Table 4.26 shows the 5 highest number of errors in the case of known errors based on the AChecker tests.

Table 4.26. The number of errors per error types

Known error type	Level of conformance	Number of errors
1.1.1. Non-text content	Level A	2052
1.3.1 Info and Relationships	Level A	376
1.4.4 Resize Text	Level AA	776
1.4.6 Contrast (Enhanced)	Level AAA	715
3.3.2 Labels or Instructions	Level A	260

4.3.4.3 Comparison of the Nibbler and AChecker tests' results

Answer to Q II/3.6: Nibbler and AChecker data tests are independent in ranks and values by countries for each individual website. We compared the results of the Nibbler and AChecker tests for the same websites. No dependence can be found. We plotted the average values of the websites by Nibbler and AChecker tests and the results can be seen in Figure 4.22 and Figure 4.23. These Figures demonstrate that no correlation can be seen between the results of the different methods.

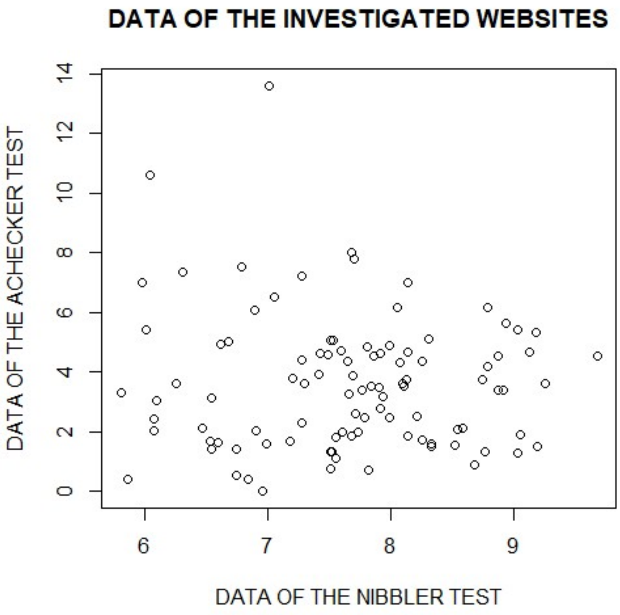


Figure 4.22. Data of the investigated websites

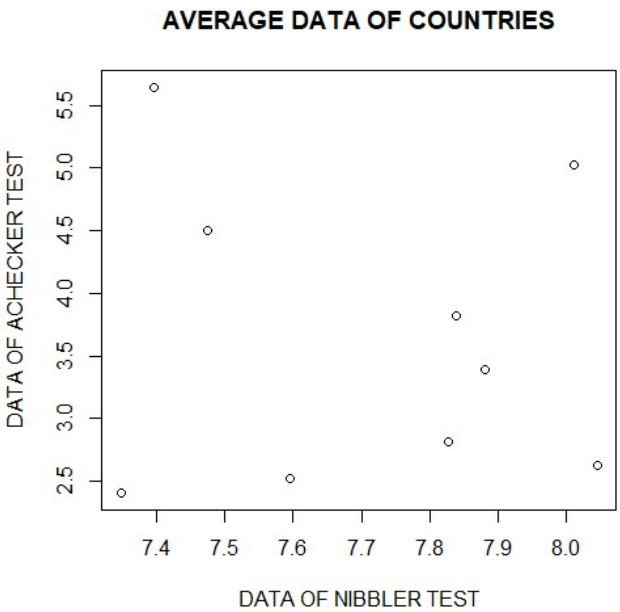


Figure 4.23. The average data of the countries

The same conclusion can be drawn based on the calculations of the tests (see Table 4.27).

Table 4.27. Covariance, correlation, and p-values between the results of Nibbler and AChecker tests investigating separate websites and countries.

	Cov.	Corr.	P-value
Separate websites	-0.12	-0.059	0.561
Countries	-0.037	-0.118	0.762

Table 4.28. The rank and the clusters of the countries according to the Nibbler and AChecker tests

	FIN	PO	HU	SWI	SWE	SLO	CZR	GER	AU
Nibbler average values	7.348	7.395	7.476	7.595	7.827	7.838	7.881	8.011	8.044
Rank	9	8	7	6	5	4	3	2	1
Nibbler cluster	3	3	2	2	1	1	1	1	1
AChecker average values	2.403	5.649	4.505	2.517	2.809	3.823	3.388	5.021	2.624
Rank	1	9	7	2	4	6	5	8	3
AChecker clusters	1	3	3	1	1	2	2	3	1

Table 4.29. demonstrates that the correlations are low, and we accept the hypothesis of the independence of both the rank and clusters on very high levels of significance.

Table 4.29. The results of testing the independence of ranks and clusters of countries provided by Nibbler and AChecker tests

	Covariance	Correlation	p-value
Ranks	-0.625	-0.083	0.831
Clusters	0.083	0.104	0.791

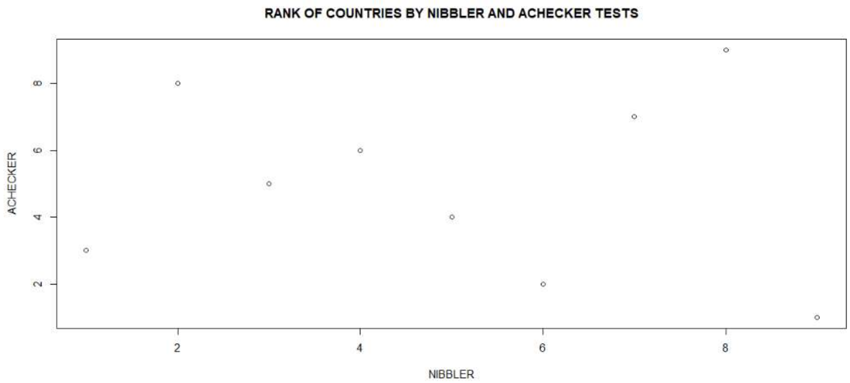


Figure 4.24. The plotted ranks

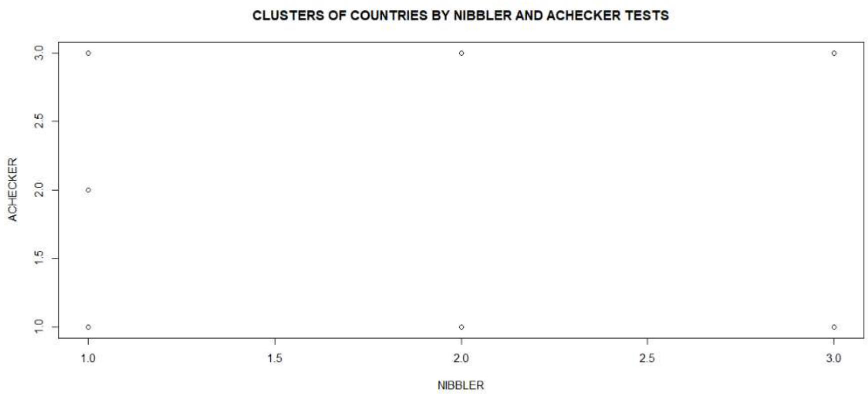


Figure 4.25. The plotted cluster numbers

4.3.4.4 Results based on the experts' tests

Answer to Q II/3.7: Following Google Chrome SEE web-application tests, we can ascertain that we found no lost information. We can state that these websites can be used equally by users who have colour-deficiency problems. The zero value in Table 4.30, column 3 confirms that there was no information loss when simulating four types of colour deficiencies, see Table 4.12, question II/3.3.

By testing the websites with Variantor special glasses, we can state that we found no information loss, these websites can be used equally well by users with colour-deficiency problems.

Answer to Q II/3.8: Based on our questionnaires, there is no usual significant difference between the V4 and the N-W-EU countries. Results focusing on countries and groups of countries are found in Table 4.12. The results are summarized in Table 4.30.

Table 4.30. The ratio of webpages satisfying special requirements in the different countries and groups of countries

Question number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**∑**
	Blind version	**Link purpose**	**Colour deficiency**	**CAPTCHA**	**Keyboard**	**English version**	**Responsive**	**Accessibility logo**	
HU	0	0.882	0	0.176	0.529	0	0.824	0	0.65
AU	0	0.875	0	0	1	0.125	1	0.125	1.25
CZR	0	0	0	0	0.875	0.125	0.875	0	1.75
FIN	0	0	0	0	0.7	0.9	0.8	0	1.5
PO	0	1	0	0.125	0.5	0	0.625	0	0.25
GER	0	1	0	0	1	0	1	0	1
SWI	0.125	1	0	0	0.688	1	0.5	0	0.06
SLO	0	0.615	0	0	0.769	0.077	1	0	1.15
SWE	0.125	1	0	0	0.625	0.25	0.75	0	0.25
V4	0	0.674	0	0.087	0.652	0.043	0.848	0	0.91
N-W-EU	0.059	0.784	0	0	0.784	0.549	0.765	0.019	0.73
TOTAL	0.031	0.732	0	0.041	0.722	0.309	0.804	0.01	0.81

Creating blind website versions has turned out to be a less convenient solution for providing accessibility. Usually the blind version is not updated frequently enough and contains old information. The applied aspects of measurement include the following: each link should be determined from the link text. E.g. “click here” or “here” is not understandable; i.e. the user could ask where they are. Success Criterion 2.4.4 Link Purpose (In Context), that is the purpose of each link can be determined from the link text alone or from the link together with its programmatically determined link context, except where the purpose of the link would be ambiguous for users in general (Level A)”.[109] Therefore, the values of the first and second columns of Table 4.30 are considered with a negative sign. Column six is not subject to analysis because of its redundant nature. Native language users of a country do not need the English version of a site for accessibility. Websites with a WAI logo were scored separately.

Only one Austrian healthcare-related governmental website contains a WAI accessibility logo among the 99 websites included in the study. This poor result may have two underlying reasons; designers either do not know about it or they do not consider it important. The fact that the WAI logo is rarely found on the investigated websites disproves the statement by Goodwin et al. [127]: "website with WAI logo have better website accessibility scores." We can state that it is not true that a website with a WAI logo has better accessibility scores.

Based on the last column of Table 4.30 (total score), it can be established that the best performing countries are the Czech Republic (total score: 1.75), Finland (total score: 1.5) and Austria (total score: 1.25), they are followed by Slovakia (total score: 1.15), Germany (total score: 1.0) and Hungary (total score: 0.65). Although the total score: 0.91 of the V4 countries was higher than the total score: 0.73 of the N-W-EU countries, there is no significant difference between them. Altogether, based on both the statistical analyses and the Nibbler results, the first three countries were Germany, the Czech Republic and Slovakia and statistics showed that the order in AChecker test result was Finland, Switzerland and Austria. This suggests that the Nibbler results are more similar to the findings of the questionnaires. This also demonstrates that for a thorough evaluation automated tests and human feedback must complement and confirm each other.

Table 4.31. Comparison of V4 and N-W-EU countries from the different perspectives (E=there is no significant difference, D=different)

Question number	**1**	**2**	**3**	**4**	**5**	**6**	**7**
	Blind version	Link purpose	Colour deficiency	CAPTCHA	Keyboard	English version	Responsive
p-value	0.095	0.220	1	0.032	0.147	7.49E-08	0.303
Decision	E	E	E	D	E	D	E

Comparing the V4 and the N-W-EU countries there are no usual significant differences between the ratios. The exceptions are the CAPTCHA function and English version availability as we take the previously mentioned calculation in Table 4.30 into account. The total score of the V4 counties is 0.91, whereas that of the N-W-EU countries is 0.73.

4.3.4.5 Results for external and internal characteristics

Answer to Q II/3.9: AChecker tests

Fig. 4.26 and Fig. 4.27 show that in the case of the AChecker test a larger size does not imply more errors. The estimated value of the correlation coefficient is 0.027, it is very close to 0. The p-value of the test is 0.791, therefore, we accept the hypothesis that these quantities do not correlate. This result is the opposite of what was concluded by Goodwin et al. in [127].

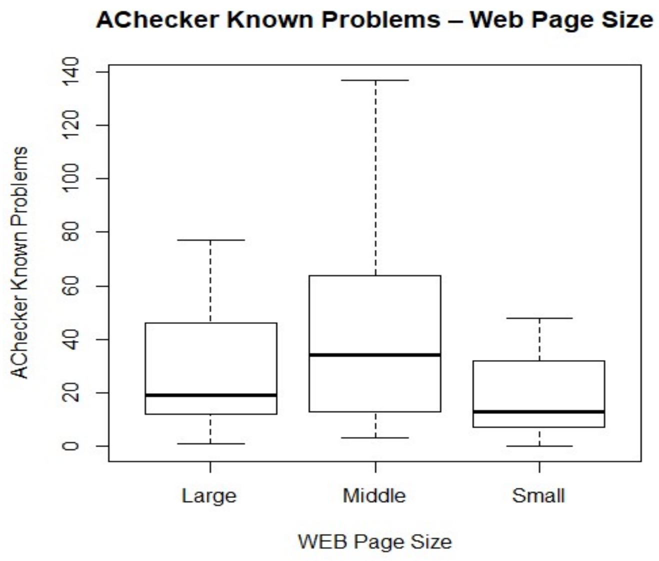


Figure 4.26. Box-plot of the AChecker-known values in the function of webpage sizes (large, medium, small)

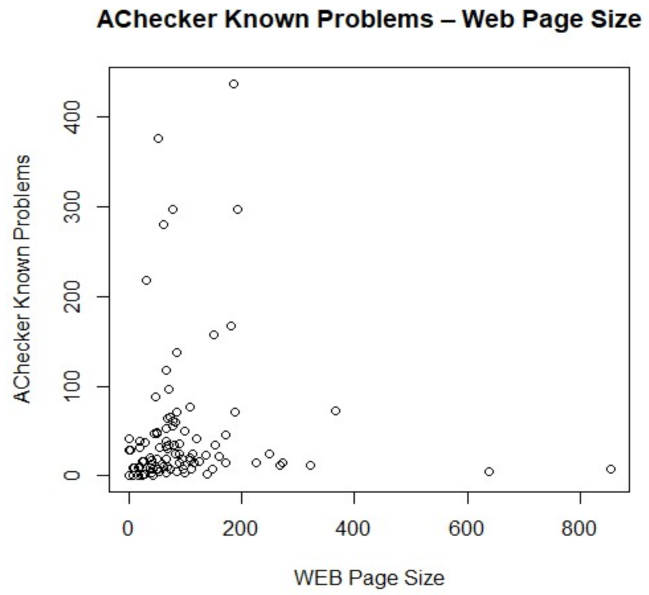


Figure 4.27. The diagram of the AChecker known values in the function of the web page sizes (Kbytes)

Concerning the Nibbler accessibility test, the opposite results can be seen in Fig. 4.28 and Fig.4.29. The trend that is suggested by the values is that smaller webpages have slightly lower Nibbler scores on average as compared to larger websites. The categories of small/medium/large were further defined by the trisection size values.

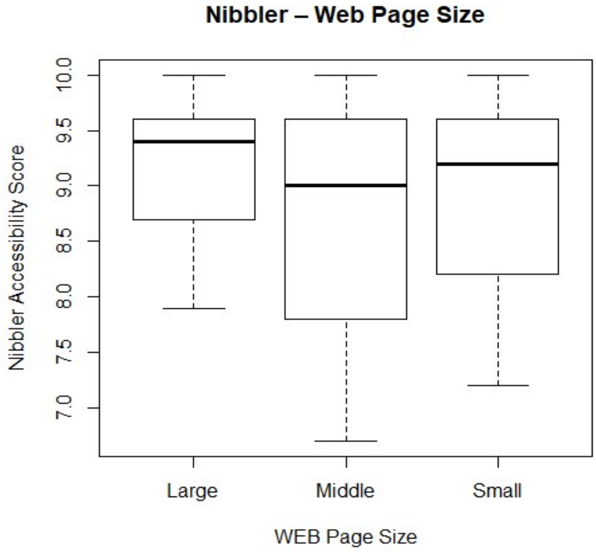


Figure 4.28. The box-plot of Nibbler Accessibility Scores in the function of the web page sizes

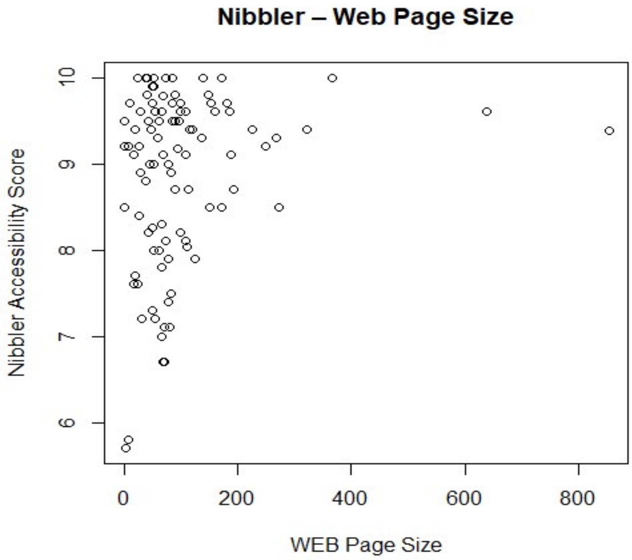


Figure 4.29. The diagram of the Nibbler Accessibility Scores in the function of the web page sizes (Kbytes)

The estimated value of the correlation coefficient is 0.226. Although it is not high, it is still significantly higher than in the case of AChecker scores. The p-value is 0.025, which is less than the usual 0.05 significance level, therefore, there is a slight correlation between size and Nibbler scores. The correlation is positive with larger websites having a higher Nibbler score. This shows that the creators of larger websites pay more attention to accessibility but the number of mistakes does not increase with the size of the webpage.

Answer to Q II/3.10: Figure 4.30 presents the number of AChecker known errors in the function of the GNI Per Capita.

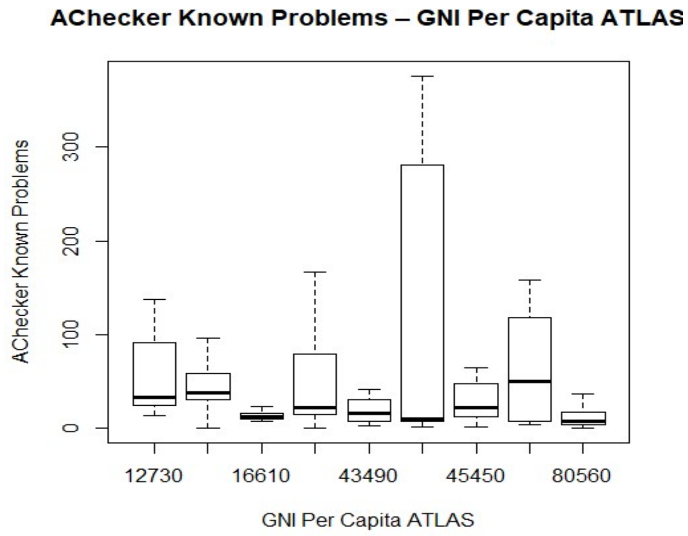


Figure 4.30. The box-plot of the AChecker-Known Problems in the function of the GNI Per Capita

The correlation coefficient is estimated to be -0.097, thus the hypothesis of independency can be accepted on a significance level of 0.169.

In the case of Nibbler tests we can notice the opposite phenomenon. The estimated value of the correlation coefficient is 0.217, which proves a slight positive correlation between the economic potential and accessibility. The hypothesis of independence is rejected; in the case of one-sided alternative hypothesis the p-value is 0.016, which confirms Goodwin et al. [127] too.

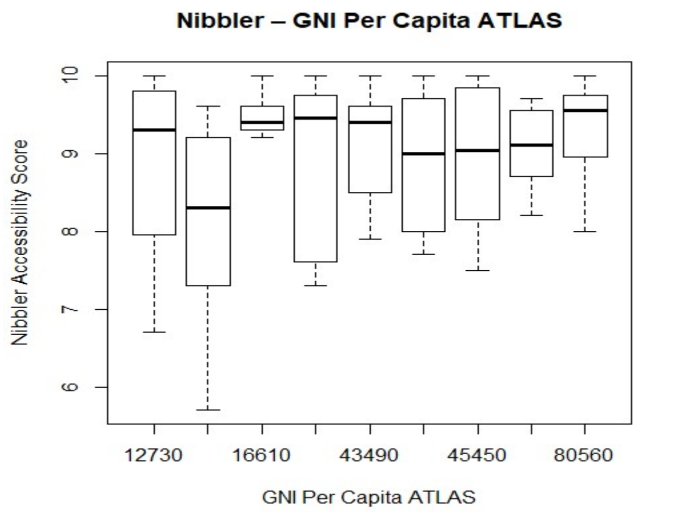


Figure 4.31. The boxplot of Nibbler Scores in the function of the GNI Per Capita

Answer to Q II/3.11: The relationships between the ratio of elderly people and accessibility were investigated by AChecker and Nibbler as well. We have not found correlations. The box-plots can be seen in Fig 4.32 and Fig 4.33.

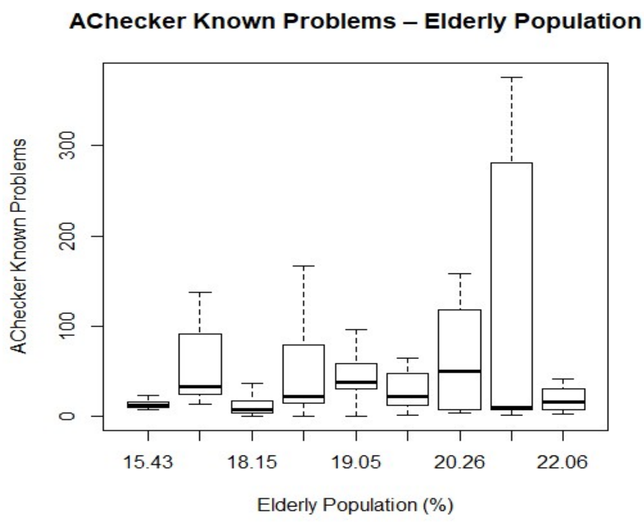


Figure 4.32. Box-plots of numbers of the AChecker Known Problems in the function of the elderly population's ratio

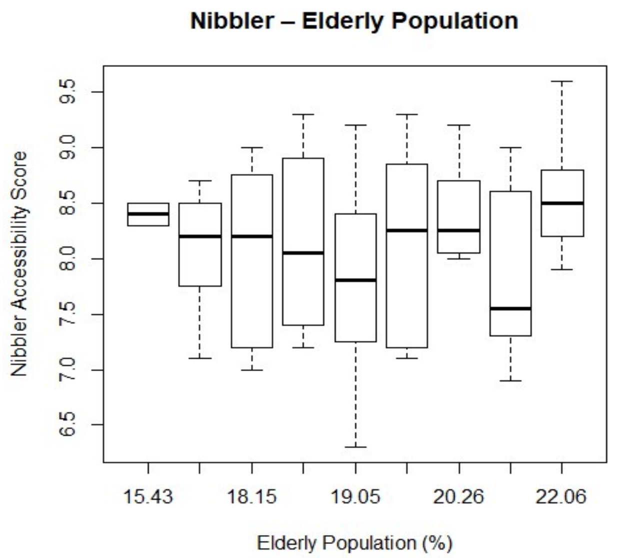


Figure 4.33. The box-plot of Nibbler Accessibility Scores in the functions of the elderly population's ratio.

The correlation coefficients are 0.166 and -0.039, respectively, so the hypothesis of independency can be accepted on the usual significance levels.

4.3.5. Discussion of accessibility testing of European health-related websites

Access to healthcare-related websites is of utmost importance to citizens all over the world, yet the present research demonstrates that people with disabilities are often excluded. Many of the accessibility problems identified in this study can be fixed relatively easily and do not require huge redesigns of the site, for example, adding appropriate ALT attributes for images. ALT tags convey the text equivalent of the image on display and are necessary for those with disabilities as they may not have the ability to physically see the image.

Providing adequate access especially to healthcare-related information is inarguably a vital task in the field of information technology. Our present research demonstrates, nevertheless, that people with disabilities are often excluded. For instance, a surprisingly large number of errors detected by AChecker (see table 4.26) concerns a major area of improvement, namely Alt attributes. ALT tags convey the text equivalent of the image on display and are necessary for those users who due to some visual impairment are not able to physically see the actual pictures themselves on the site. Alt attributes are responsible for what the screen reader can read in such cases as an alternative text about an image. The guidelines for implementation, handling and problem resolution are clearly stated in WCAG 2.0. [109], which already classifies Alt tags as a Level A area. Identifying and remedying Alt tag issues, as accessibility problems, is a relatively simple task and does not require huge redesigns of the site.

"Success Criterion 1.1.1 Non-text Content (Level A): All non-text content that is presented to the user has a text alternative that serves the equivalent purpose." [109] "Success Criterion 1.3.1 Info and Relationships (Level A): Information, structure and relationships conveyed through presentation can be programmatically determined or are available in text." [109] "The intent of this Success Criterion is to ensure that information and relationships that are implied by visual or auditory formatting are preserved when the presentation format changes. For example, the presentation format changes when the content is read by a screen reader or when a user style sheet is substituted for the style sheet provided by the author." [109] "Success Criterion 1.4.4 Resize text (Level AA): Except for captions and images of text, text can be resized without assistive technology up to 200 percent without loss of content or functionality." [109] "The intent of this Success Criterion is to ensure that visually rendered text, including text-based controls can be scaled successfully so that it can be read directly by people with mild visual disabilities, without requiring the use of assistive technology such as a screen magnifier. Users may benefit from scaling all content on the Web page, but text is most critical." [109] "Success Criterion 1.4.6 Contract (Enhanced) (Level AAA): The visual presentation of text and images of text has a contrast ratio of at least 7:1." [109]

From the data collected and analyzed on the basis of both our questionnaires and the figures produced by the applied automated tools, we accept hypotheses: H II/3.1, H II/3.4, H II/3.5, H II/3.6, H II/3.7, H II/3.8 and H II/3.11.

The answer is mixed for H II/3.3. For two sub-problems the first part of H II/3.3 is accepted, for another two it is rejected. For a few questions of the second part of H II/3.3 is rejected, but in the most cases it is accepted. H II/3.9 and H II/3.10 are mixed again.

4.3.5.1 Accepted hypotheses

Taking into account our response to research question Q II/3.1, documented in Table 4.14, Table 4.15 and Table 4.16, it can be claimed that there is no significant difference between the expectations in the groups of countries. So, we formulate T II/3.1. **T II/3.1**: The expectations of the scores of the V4 countries and the N-W-EU countries regarding the aspects separately are equal. There is no significant difference. H II/3.4 is also acceptable. **T II/3.4**: The average number of errors are equal comparing V4 and N-W-EU countries in case of each conformance level versus they are different. The most frequently violated success criterions are 1.1.1 Non-text content, 1.3.1 Info and Relationships, 1.4.4 Resize Text and 1.4.6 Contrast (Enhanced) (see Table 4.26), which are all known problems, they belong to Principle 1. So, H II/3.5 is true. **T II/3.5**: Most errors originated when web developers violated Principle 1 – that is, web developers do not provide a text alternative to any non-text content. We accept H II/3.6 because the independence of the two evaluations can be accepted both in case of the websites and countries. It is proven by Figure 4.22, Figure 4.23, Figure 4.24, Figure 4.25 and Table 4.27, Table 4.28, Table 4.29. **T II/3.6**: There is no correlation between Nibbler and AChecker evaluations, either in ranks or in values. Regarding the answers to questions Q II/3.7 and concerning H II/3.7 hypothesis we can state the following thesis about the colour design of the investigated websites. **T II/3.7**: Users with colour-deficiencies are able to use the investigated websites the same way as people with no vision impairment (here we applied SEE and Variantor glasses). **T II/3.8**: There is no significant difference between the N-W-EU and V4 countries based on the evaluation of the experts' questionnaire (see Table 4.30). **T II/3.11**: There is no connection between the ratio of elderly populations and web accessibility, even though elderly people need more accessible web pages (see Fig. 4.32 and Fig 4.33).

4.3.5.2 Mixed cases

We agree with the first part of H II/3.2 because the scores show medium positive correlations numerically in the case of V4, N-W-EU countries and all countries. (See Table 4.16 and Table 4.17.)

We reject the second part of H II/3.2. In most cases the correlation between the different aspects cannot be considered zero, therefore, the scores gained at different aspects are not independent. In the case of the two-sided alternative hypothesis the only exception is the Marketing-Technology pair in the case of the V4 countries. Therefore, in the case of any other pairs we can state that on average a larger score for a certain aspect implies larger score for another one.

Consequently, we formulate **T II/3.2** as follows: Better technology results in higher accessibility in numerical values. Although numerically the average number of errors of the N-W-EU countries is higher in the case of level A than that of V4 countries and the opposite is true for level AA and AAA, statistically there are no significant differences between the expectations. (Table 4.24 and Table 4.25 show the results.) Larger score for one aspect implies larger score for another one, except for Marketing and Technology in the V4 countries.

T II/3.3: There are no significant differences in the case of known and likely problems. Considering the numbers of errors of all types, we can state that the expectation is larger in case of V4 countries than in the case of N-W-EU countries. The most frequently affected guidelines are Non-text content, Resized text and Contrast. Non-text content means that there is no verbal explanation for the figures. Success Criterion "1.4.4 Resize text (Level AA)"and Success Criterion "1.4.6 Contract (Enhanced) (Level AAA)" (see Table 4.26) were detailed in the first paragraph of the Discussion (4.3.5.1). The expected numbers of the above errors can be considered the same in case of V4 and N-W-EU countries.

The scores are not country specific and not country group specific. There is a high degree of variation among individual webpages in the same countries. This implies that there are very well and there are particularly poorly performing sites in each country. There is no correlation between Nibbler and AChecker results. Although they do not measure the results based on the same algorithms, it is necessary to compare them since they complement each other, and they allow us to ascertain which one yields similar results to the applied questionnaires. AChecker tests investigate mainly programming solutions, while Nibbler takes user experience into account, therefore, correlates more to the conclusions drawn on the basis of user feedback. This comparison helps web developers decide which test serves their goals better, depending on what they want to test.

We also performed the tests designed by Goodwin et al. [127] for investigating the relation between size and accessibility. The result is mixed: we accept the hypothesis of the independence of size and accessibility if we measure accessibility by AChecker, but if independence is measured by Nibbler we reject the previous statement and accept the notion that size and accessibility go hand in hand. **T II/3.9**: The size of the webpage does not correlate with the number of the known errors indicated by AChecker, larger websites do not contain more errors than smaller websites. Larger websites, however, have better accessibility if the accessibility is characterized by Nibbler scores.

Q II/3.10 is motivated again by Goodwin et al. [127]. We investigated the relation between economic potential and accessibility. We found that H0 is accepted if accessibility was measured by AChecker, and H0 is rejected if the accessibility was characterized by Nibbler scores.

T II/3.10: The effect of the economic potential of a region cannot be demonstrated in AChecker tests, but it can be presented in the results of the Nibbler test. The countries with higher GNI per capita have more accessible websites by Nibbler.

4.3.6 Conclusion of accessibility testing of European health-related websites and extension of the recommendations of accessible web design

The element of innovation this research presents is that is looks at some relevant accessibility issues concerning health-related websites in different historical and economic regions in Europe. Such a detailed statistical comparison has not yet been carried out in Europe for testing healthcare-related websites, even though their regular revision seems necessary owing to the demands of the growing elderly population. The authors would also like to draw attention to the fact that the two applied automatic testers yielded different accessibility results for the same sites, therefore, statistical evaluation based on user response has proven inevitable for thorough analysis.

This research demonstrates that the vast majority of healthcare-related websites in the North-West-European (N-W-E) and V4 countries (Czech Republic, Hungary, Poland, Slovakia) does not meet industry-related accessibility guidelines. Most of the websites in this research violated the same guidelines because their designers did not take the needs of people with disabilities into account. Consequently, these websites contain almost the same, very common errors. Accessibility errors should be identified by software testing tools based on WCAG 2.0 and user response. We did not find differences between the results of N-W-EU and V4 countries, in spite of the fact that the GDP and GNI of the N-W-EU countries are much higher than the GDP and GNI of V4 countries.

First of all, the findings in this paper might help web designers by providing a better understanding of their websites and can also be used to facilitate assessing web accessibility. Second, if service or software development has been carried out without taking the requirements of accessibility into consideration, it is certain that the result will not be an accessible solution and accessibility problems will emerge. The accessibility problems will remain until an expert in accessibility gives instruction to web designers, otherwise web designers will have to familiarize themselves with all accessibility guidelines. There is no doubt that users with special needs are not involved in the design process and the testing of the usability of websites. Furthermore, it is clear that the cost of developing accessible websites from the first step of the design process is much cheaper than to redesign or transform the badly designed website and make it accessible.

All our measurements and research are based on the WCAG 2.0 guidelines, meanwhile, the newest version WCAG2.1 [180,181] has just been released. In the future, this research should be repeated based on WCAG 2.1, but currently there is a lack of effective automatic test tools based on WCAG2.1.

Unfortunately, the identified known, likely and potential problems, errors have not changed for the last 10 years compared to our earlier research. [17,37] My recommendation still holds. [17,37] (see subchapter 4.2.4.)

I am hereby extending my earlier recommendations by adding two additional Points:

- xi. **All websites must be made responsive so that they can be accessed by any device or platform independently of screen size.**
- xii. **Websites should be tested with real users. Involve people with disabilities in the research, design and development process. Include different disabilities with the help of:**
  - **focus groups**
  - **usability tests**
  - **design and research team.**

I summarise the subthesis based on the 4.3 subchapter:

Subthesis II/3. For website accessibility testing of European health related websites I offer a dual measurement system combining both the application of automated testing software and user feedback. For that I have developed an expert questionnaire to test web pages. I have extended my previous recommendation with two new points. [4] Moreover I have disproved Goodwin et al.'s thesis [127] that the wealthier a country is (GNI per capita), the fewer barriers will be present on its websites and the larger size of webpages in Kbytes is, the larger barriers will be presented on its websites. So, I have demonstrated that the design of accessible websites is independent of the economic situation and webpages size and also demographic needs. [4]

T II/3.1: The expectations of the scores of the V4 countries and the N-W-EU countries regarding the aspects separately are equal. There is no significant difference.

T II/3.2 Better technology results in higher accessibility in numerical values. Although numerically the average number of errors of the N-W-EU countries is higher in the case of level A than that of V4 countries and the opposite is true for level AA and AAA, statistically there are no significant differences between the expectations. Larger score for one aspect implies larger score for another one, except for Marketing and Technology in the V4 countries.

T II/3.3: There are no significant differences in the case of known and likely problems. Considering the numbers of errors of all types, we can state that the expectation is larger in case of V4 countries than in the case of N-W-EU countries. The expected numbers of the above errors can be considered the same in case of V4 and N-W-EU countries.

T II/3.4: The average number of errors are equal comparing V4 and N-W-EU countries in case of each conformance level versus they are different.

T II/3.5: Most errors originated when web developers violated Principle 1 – that is, web developers do not provide a text alternative to any non-text content.

T II/3.6: There is no correlation between Nibbler and AChecker evaluations, either in ranks or in values.

T II/3.7: Users with colour-deficiencies are able to use the investigated websites the same way as people with no vision impairment.

T II/3.8: There is no significant difference between the N-W-EU and V4 countries based on the evaluation of the experts' questionnaire.

T II/3.9: The size of the webpage does not correlate with the number of the known errors indicated by AChecker, larger websites do not contain more errors than smaller websites. Larger websites, however, have better accessibility if the accessibility is characterized by Nibbler scores.

T II/3.10: The effect of the economic potential of a region cannot be demonstrated in AChecker tests, but it can be presented in the results of the Nibbler test. The countries with higher GNI per capita have more accessible websites by Nibbler.

T II/3.11: There is no connection between the ratio of elderly populations and web accessibility, even though elderly people need more accessible web pages.

In conclusion, a site that meets accessibility requirements opens the market to a wider range of customers. If we look at the growing number of elderly people, their demand for accessible websites can be expected to increase. If companies do not focus on these requirements, they will lose a high number of their customers. The overall benefit is that of increased value. The issues identified in this study can also be considered to be independent of financial considerations, since they require only a bit of attention and the willingness to identify the needs of people with disabilities.

Chapter 5

Universal design and accessibility in e-health-related applications

This chapter is based on my previous publications: ten journal papers [2,15], [18-24], [29] and eleven publications in conference proceedings [39], [44-53].

The goal of this chapter is twofold. Firstly, the research field is related to universal design and accessibility. Secondly, it shows application areas of helping people with several disabilities. The application areas are based on three international collaborations.

The first part of this chapter shows the research under the umbrella of the “Game On Extra Time project”. The project supports people with learning disabilities and additional sensory impairments in their daily activities, via games-based learning. For that we have developed several VR games. In this research I have addressed questions related to the design and evaluation of such games and my design solutions to suit the individual needs of the target audiences.

The second part of this chapter describes the research work in the “Telemedicine System Empowering Stroke Patients to Fight Back” project. This project provided us the essentials to create many VR- and multimedia-based games, and motivational-educational animations. During this project I contacted not only therapists but also patients with special needs and skills were also taken into consideration. That is how I formulated the functional and non-functional requirements of such games and created a new method which is based on the continuous feedback from the users.

The third part of the chapter is the practical and theoretical evidence of how an accessible website could be developed for healthcare. The purpose of this pilot study was to determine the usability, utility, and feasibility of a website we created to increase engagement and improve the quality of the preoperative education patients receive in preparation for hip and knee arthroplasty. The usability of the developed website based on the Perceived Health Website Usability Questionnaire online survey was performed. The paper-based survey contains ten questions using a 7-point Likert scale, while the web-based survey contains fourteen questions using the same 7-point Likert scale. Descriptive statistics and independent samples t-tests were used for comparative analysis of usual paper education and website education cohorts. According to the survey results for the nursing staff, they believed that the use of the website improved nursing workflow, efficiency, and patient education.

5.1 User interface evaluation of serious games

5.1.1. Introduction user interface evaluation of serious game

Ten serious games have been designed and evaluated under the EU Leonardo Transfer of Innovation Project: Game On Extra Time (GOET) project [128]. The project supports people with learning disabilities and additional sensory impairments in getting and keeping a job by helping them to learn, via games-based learning, skills that will help them in their working day. These games help students to learn how to prepare themselves for work and for dealing with everyday situations at work, including money management, travelling independently etc.

People with intellectual disabilities often face a lack of control and opportunity in their everyday lives, with less than 10% having jobs [245]. People with Intellectual Disabilities experience low levels of employment and face barriers to employment. The UK Valuing People Report [246] and the Learning for Living and Work Report [247] have emphasised the need to promote and develop appropriate training and employment opportunities for this target audience. The Game On Extra Time (GOET) project provides a response to these calls, by the development of engaging and accessible serious games to develop work-based skills in this target audience.

In this research I have addressed questions related to the design and evaluation of such games and our design solutions to suit the individual learning needs of our target audiences. It is necessary to design the user interfaces for maximum accessibility and usability. In this way we minimised the additional cognitive load placed on the user when navigating within the software. In order to achieve these goals I have followed published design guidelines and placed emphasis on using graphics, animations, interactivity, choice and auditory output to promote user engagement and provide alternatives to text. In this chapter I will address the pilot testing of the user interface of these serious games.

These games, which are tested in all partner countries (UK, Lithuania and Hungary), include [42]:

- 3D Work Tour: simulating the first days at work in a games 'mod' created using the Half Life 2 engine
- Cheese factory: teaching the students using fractions and percentages based on the popular Tetris Game.
- Memobile: trains the student in the important things to do in preparing to leave the house and throughout their working day using mobile phone technology programmed using Flash.
- My Appearance: covering everyday routines such as personal hygiene and getting ready for work-tasks, from getting up until leaving home, using a Flash game.
- VR supermarket: helps to teach students about money management skills within a store environment, developed using Flash.

Five more games were developed but were not tested in every partner countriy. These are "Anger management", "Personal Hygiene", "Starting Work", "Stress at work" and "Work Sustainability".

Today, game design also involves a focus on traditional usability such as creating clear terminology as well as non- intrusive, easy-to-use user interfaces [248]. While more than ten principles are under consideration, a preliminary subset of the Game Approachability

Principles (GAP), aimed at better engaging casual gamers, is shown below. This specific "shortlist of six" GAP was formulated in keeping with leading learning theories such as [249] Social Learning Theory [250] Self-efficacy, another key concept and term used in education and learning.

Game Approachability Principles (GAP) for Improving Game Approachability [251]:

- (1) Observation and Modelling;
- (2) Self Efficacy;
- (3) Game Based Principles (Identity, Manipulation and Perception);
- (4) HELP and PLAY Based Guidelines (such as players not being penalized repetitively for the same failure; varying activities and pacing during the game to minimize fatigue or boredom; etc.);
- (5) Demonstrate Actions and Reinforcement;
- (6) Likeability of the Tutorial

My questionnaire was focused more or less on GAP 1-5 principles.

A key component of usability engineering is setting specific, quantitative usability goals for a product early in the process and then designing to meet those goals [252]. There are typically four different activities that every project engages in during a system development process (Planning, Analysis, Design and Evaluation). Most system development projects include these activities, or at least similar activities that could be easily identified as one of these four.

When the consideration of people with disabilities is included in the design process, it is usual to talk about "Design for all", "Universal Usability" or "Equitable Use", implying that the design should be useful and marketable to any group of users [253]. However, Newell and Gregor [254] consider that this ideal may be very difficult if not impossible to achieve. For example, different user groups may provide very conflicting requirements for a product. As an alternative, they propose a "User Sensitive Inclusive Design", which recognises that inclusivity is more achievable than a universal design. One of their conclusions is that, "User Sensitive Inclusive Design needs to be an attitude of mind rather than simply mechanistically applying a set of 'design for all' guidelines." With this in mind, we employ a methodology for the development of games-based learning which was determined by combining established guidelines on user-centred design e.g. INUSE [255] and USERfit [256] with contemporary human-computer interaction and product design research.

One of my goals was with the testing, to make clear the tasks for redesigning the games before the pedagogical testing. The usability testing of the developed 10 serious games' user interface is written in this chapter. The research question regarding this study is how a useful user questionnaire could be developed.

5.1.1.1. Why are serious games appropriate tools for people with intellectual disability?

According to the 2001 Department of Health White Paper [257], people with intellectual disabilities are amongst the most socially excluded and vulnerable groups in Britain, and this is unlikely to differ in other countries. Very few have jobs, live in their own homes or have real choice over who cares for them. Today, the majority no longer live in institutions but in the family home and, although their individual needs will differ, there is an expectation that they will achieve greater independence and greater inclusion in society [257]. The intention of current policy is to enable them to have as much choice and control as possible over their lives, to be involved in their communities and to make a valued contribution to the world at work. However, in order to achieve these aims, their education needs to equip them with appropriate skills. The Tomlinson Report [258] highlighted the need to provide courses which teach independent living and communication skills, and this need has been reiterated by others [259].

For people with intellectual disabilities, computer-based learning has a huge contribution to make. According to Hawkridge and Vincent [260], it enables pupils to take charge of their own learning, and they will find stimulation through 'enjoyable repetition' and a gradual increase in level of challenge. Blamires [261] argues that enabling technology provides access to educational opportunities and life experiences and facilitates engagement with knowledge and people: "Speech, pictures, words, and animation can be combined in interactive ways to structure concepts to suit the level of understanding of learners and their interests." [245] Thus it facilitates alternative methods of supplying information, which may help this group of people grasp more complex concepts. This is of particular importance for learners who may have a poor grasp of language, and its abundance of visual opportunities makes it particularly suitable for those with little or no hearing. [245] Additionally, the use of games-based learning has been promoted for people with Intellectual Disabilities. Originally, the majority of the research on computer games focused on the negative aspects [262]. Pivec [263] makes the point that while it is widely recognised that games have an important role in early learning, as education becomes more formal, games tend to be seen as just an "unserious activity" (p. 387). In a review of both the positive and negative effects of playing videogames, Griffiths [264] describes the role of videogames in cognitive rehabilitation, for example in perceptual disorders, conceptual thinking, attention, concentration and memory in patients with brain damage following stroke or trauma. More recent studies have produced empirical evidence to demonstrate the efficacy of games-based learning in the cognitive rehabilitation of people with intellectual disabilities, to improve choice reaction time [265], independent decision making [266] and working memory [267]. One of the primary advantages of games in learning is their ability to engage the learner voluntarily in sufficient repetitions of the activities to ensure learning takes place. [263] This is what Garris et al. [267] termed persistent reengagement, where the player returns to the task unprompted. In short, computer-based instruction, and more importantly games-based learning, can make a very real contribution to teaching essential life and work-based skills to people who struggle to find other ways of learning these skills, and the usability evaluation of such games is essential if we are to make them fit for use by this very specific target audience.

5.1.2. Short description of the tested games

In this section the main design requirements of the tested games, "Cheese factory", "My Appearance", "3D Work Tour", "VR supermarket", "Memobile", "Anger management", "Personal Hygiene", "Starting Work", "Stress at work" and "Work Sustainability", are described. Screenshots of the tested games are available in [22], [42,43].

Cheese Factory game: The Goal of the Cheese Factory Game is to teach percentages, fractions and decimals. Players are challenged to match the falling shape with the shapes distributed along the bottom of the interface to form a whole 'cheese'. Initially the challenge is one of shape matching by using the arrow keys to position the shapes along the bottom of the interface with the falling shape. This matching challenge addresses the underlying 'language of fractions'. Later, the challenge of the game is increased, where the falling shapes become amorphous, and players are challenged to match the falling number (without the added benefit of the appropriate shape to indicate value), expressed as either a percentage, fraction or decimal, as we move to fractional notation. This replicates the real-world steps when teaching these concepts to students with special educational needs. The game can be played at varying speeds and has increasing levels or challenge to make it scalable for a wide range of abilities. Cheese factory teaches the students to use fractions and percentages based on the popular Tetris Game. The user interface of this game is simple too. The instructions are clear, the colours are appropriate, and they are in harmony with the overall interface. The users' results are shown on the right side of the game, and the next piece of the cheese is also shown. These features support the user in their on-going learning tasks.

My appearance game: My Appearance teaches the students everyday "morning" tasks, from getting up until leaving home, using a Flash game. The graphic interface of the game is clear and understandable and cartoon-like. It simulates the sequencing of morning tasks in preparation for leaving for work, and the structure of the game is very consistent. For example, after getting up, having a shower, getting dressed and eating breakfast, the user's avatar is ready to leave for work and its appearance improves. At the end of the game the user receives feedback on his/her performance using sound, subtitles or BSL. If the student forgets to wash his/her hands or forgets to have a morning drink, the game doesn't interfere – it lets the student make mistakes and learn from doing so by reflecting on the game responses to their actions.

3D Work Tour game: 3D Work Tour simulates the first days at a workplace in a games 'mod' created using the Half Life 2 engine. After selecting the language there are two possibilities: subtitles and video tour with BSL (British Sign Language) for hearing impaired users. The user interface is very simple and very clearly organised. The VR environment and avatars are realistic and look similar to the work-based environments and people in the real world.

VR Supermarket game: The VR supermarket game helps to teach students about money management skills within a store environment developed using Flash. The player enters the virtual supermarket and is given a virtual wallet, shopping list and shopping cart. The goods on a given shelf are displayed with their names, prices and images attached to them. To place an item to the shopping cart, the player only has to click on the given item. Before paying, the bar code scanner registers the price of each item in the shopping cart one by one. During this step, both the cashier and the cash register will give feedback to the student. To pay for the items, the student has to place a sufficient sum of money onto the drop panel by clicking the separate banknotes and coins in the wallet and then hitting the pay button.

Memobile game: The Memobile game trains the student in the important things to do in preparing to leave the house and throughout their working day, using mobile phone technology programmed using Flash.

Anger Management game (with English BSL): This set of content uses opposed video sketches that the player must choose between. The topics cover: Discipline, Peer pressure, Bullying, Frustration and Stress. Selection uses the "True" or "False" approach, the player should choose the clip showing the most appropriate behavior.

Personal Hygiene game: This is a very simple set of content. It comprises 7 personal hygiene statements that are answered as “True” or “False”. The play begins with a brief preamble and some simple usage instructions. Each of the seven statements has a relevant background image. The “True” and “False” locations are randomly assigned. After answering “True” or “False”, a feedback statement is given; a correct answer is associated with a green smiley face, a wrong answer is associated with a red sad face.

Starting Work game: This game simulates the player’s home and presents a number of multiple-choice questions relating to getting ready to start work, in the appropriate locations around a house. These locations are the bedroom, bathroom, kitchen and living room. When the player chooses to leave the house, they receive a summary of how they performed, plus the option to save a report of their progress as a PDF.

Stress at Work game (with BSL): This game uses animated content (swf files) and the “conveyor” interaction to present two or more optional answers covering issues of stress at work. 8 topics are covered. The game begins with a brief preamble and fairly detailed usage instructions, in text and BSL. During the game, the player uses the left or right arrows to move the conveyor at the bottom of the screen and the space bar to select (alternatively, clicking on an un-highlighted answer brings it to the central location and highlights it; clicking again selects it). Once a response has been chosen, feedback is given. A correct answer is accompanied by a smiley face and the answer associated with that issue. Once all 8 items have been answered, the user reaches the feedback screen again.

Work Sustainability game: This game is “Getting and Keeping a Job”. This has a slightly longer set of content. It comprises 4 sections, with topic-specific statements that are answered as “True” or “False”. These topics are: Getting a Job (7 statements), Starting Work (9 statements), Getting ready for work (3 statements), Your working day (10 statements). Each of the sections has a relevant background image. The “True” and “False” locations are randomly assigned. After answering “True” or “False”, a feedback statement is given; a correct answer is associated with a green smiley face, a wrong answer with a red sad face.

5.1.3. Evaluation of the user interface

There are objective and subjective evaluation methods, for example Heart Rate Variable based method [29]. We used subjective method based on questionnaire.

I have developed a 5-point Likert Scale close-ended questionnaire for testing the user interface of the newly developed serious games.

Likert Scales: Likert scales are scales on which the participants register their agreement or disagreement with the statement. “_Strongly Disagree (1), _ Disagree (2), _Neither Agree nor Disagree (3), _ Agree (4), _Strongly Agree (5)” on a five-point scale.

This questionnaire contains 29 questions arranged in 4 themes.

- To what degree are the games enjoyable? (6 questions)
- Questions concerning the usability of the software (4 questions)
- Questions concerning the software’s manageability: (9 questions)
- Questions concerning the graphics (10 questions)

If the sentence has a negative meaning, for example, “The noises or music used in the games were disturbing.”, we converted the user’s answer. Because if the user answer is

"Strongly Agree (5)", the answer has negative content, it should not get the best 5 points, only the minimum 1 point.

The negative meaning questions are:

- Using the software was tiring (Table 5.1).
- Playing with the software was boring (Table 5.3).
- The noises or music used in the games were disturbing (Table 5.14).
- Failures were typically results of disorientation (Table 5.16).
- Failures were typically results of not being able to recognise pictures (Table 5.26).
- Failures were typically results of not understanding instructions (Table 5.27).

The questionnaires were filled in by 8-15 specialists of psychology, teachers, spec. pedagogy, and IT administrators from Lithuania, Hungary and the United Kingdom. The specialist scored the games. The mean and standard deviation (STD) of these scores are written in the table 1-29 in the following section. The scores are between 1.57 and 4.86. The smallest score is 1.57 (Table 5.1-5.2) with STD=0.53 and STD=1.57. The highest score is 4.86 (Table 5.17-5.18) with low STD=0.36.

5.1.3.1. To what degree are the games enjoyable (6 questions)

How engaging are the games?

Table 5.1. Using the software was tiring

game	mean	STD
Cheese factory	1.57	1.16
My Appearance	3.21	1.76
3D Work Tour	3.08	0.51
VR Supermarket	2.43	1.79
Memobile	3.07	1.20
Anger Management	3.80	0.63
Personal Hygiene	4.0	1.41
Starting Work	2.71	0.99
Stress at work	4.56	0.53
Work Sustainability	3.63	0.52

Table 5.2. The content of the software was engaging

game	mean	STD
Cheese factory	1.57	0.53
My Appearance	3.21	0.85
3D Work Tour	3.08	1.19
VR Supermarket	2.42	1.49
Memobile	3.07	0.47
Anger Management	3.80	0.63
Personal Hygiene	4.00	1.69
Starting Work	2.71	0.61
Stress at work	4.55	0.93
Work Sustainability	3.63	0.52

Table 5.3. Playing with the software was boring

game	mean	STD
Cheese factory	3.50	1.22
My Appearance	2.71	1.38
3D Work Tour	2.42	1.31
VR Supermarket	2.36	1.50
Memobile	3.86	1.10
Anger Management	3.50	0.71
Personal Hygiene	4.23	0.93
Starting Work	2.86	0.66
Stress at work	3.33	0.50
Work Sustainability	2.38	0.52

Table 5.4. The games were easy to play

game	mean	STD
Cheese factory	4.85	0.36
My Appearance	4.57	0.65
3D Work Tour	3.42	0.67
VR Supermarket	4.50	0.94
Memobile	3.43	1.16
Anger Management	3.90	0.86
Personal Hygiene	3.92	1.55
Starting Work	3.57	0.94
Stress at work	3.78	0.83
Work Sustainability	4.00	0.00

Table 5.5. Activities in game play were predictable

game	mean	STD
Cheese factory	2.71	1.20
My Appearance	3.00	0.96
3D Work Tour	3.25	0.45
VR Supermarket	3.71	1.20
Memobile	1.64	1.08
Anger Management	3.00	0.47
Personal Hygiene	2.15	1.41
Starting Work	3.21	0.80
Stress at work	3.00	0.00
Work Sustainability	2.00	1.07

Table 5.6. I used the software willingly

game	mean	STD
Cheese factory	4.71	0.61
My Appearance	3.71	1.07
3D Work Tour	2.33	1.30
VR Supermarket	4.42	1.02
Memobile	3.36	1.45
Anger Management	3.60	0.52
Personal Hygiene	3.46	0.78
Starting Work	2.85	0.77
Stress at work	3.33	0.50
Work Sustainability	3.00	0.00

5.1.3.2. Questions concerning the usability of the software (4 questions)

Questions regarding the usability of the software:

Table 5.7. The software displays realistic situations

game	mean	STD
Cheese factory	3.14	0.86
My Appearance	4.00	0.68
3D Work Tour	3.83	0.72
VR Supermarket	3.86	0.77
Memobile	3.36	1.00
Anger Management	4.00	0.00
Personal Hygiene	4.15	0.99
Starting Work	3.79	0.43
Stress at work	3.89	0.33
Work Sustainability	4.00	0.00

Table 5.8. The presented situations were relevant and important

game	mean	STD
Cheese factory	3.71	0.61
My Appearance	4.14	0.66
3D Work Tour	3.67	0.65
VR Supermarket	3.64	0.74
Memobile	3.43	0.76
Anger Management	4.30	0.48
Personal Hygiene	4.30	0.63
Starting Work	3.79	0.43
Stress at work	4.00	0.00
Work Sustainability	4.00	0.00

Table 5.9. Are you satisfied with the quantity and diversity of the questions used?

game	mean	STD
Cheese factory	3.36	0.63
My Appearance	3.29	1.14
3D Work Tour	3.27	0.65
VR Supermarket	3.36	1.00
Memobile	3.07	0.73
Anger Management	3.40	0.52
Personal Hygiene	3.62	1.45
Starting Work	2.64	0.63
Stress at work	2.78	0.67
Work Sustainability	3.38	0.52

Table 5.10. Using the software was easy

game	mean	STD
Cheese factory	4.57	0.65
My Appearance	3.86	0.95
3D Work Tour	3.50	0.67
VR Supermarket	4.21	0.58
Memobile	3.50	1.51
Anger Management	4.10	0.57
Personal Hygiene	3.92	1.19
Starting Work	3.50	0.85
Stress at work	4.00	0.87
Work Sustainability	4.00	0.53

5.1.3.3. Questions concerning the software's manageability (9 questions)

Questions regarding the software's manageability:

Table 5.11. There is sufficient opportunity to correct or revisit responses given in the game

game	mean	STD
Cheese factory	3.71	0.83
My Appearance	3.64	1.08
3D Work Tour	3.58	0.90
VR Supermarket	4.07	0.47
Memobile	3.36	1.08
Anger Management	3.90	0.32
Personal Hygiene	3.77	1.09
Starting Work	3.64	0.63
Stress at work	4.00	0.00
Work Sustainability	4.00	0.00

Table 5.12. The content areas between levels are distinct

game	mean	STD
Cheese factory	3.86	0.36
My Appearance	3.29	1.07
3D Work Tour	3.58	0.90
VR Supermarket	3.43	0.85
Memobile	3.36	0.84
Anger Management	3.10	0.32
Personal Hygiene	3.69	1.18
Starting Work	3.21	0.80
Stress at work	3.11	0.33
Work Sustainability	3.00	0.00

Table 5.13. It was easy to follow the activities in the game

game	mean	STD
Cheese factory	4.07	0.73
My Appearance	4.00	0.88
3D Work Tour	3.67	0.89
VR Supermarket	4.21	0.43
Memobile	3.50	0.85
Anger Management	3.90	0.32
Personal Hygiene	3.00	1.47
Starting Work	3.57	0.85
Stress at work	4.00	0.50
Work Sustainability	1.41	1.07

Table 5.14. The noises or music used in the games were disturbing

game	mean	STD
Cheese factory	4.64	0.74
My Appearance	3.90	0.99
3D Work Tour	4.36	0.92
VR Supermarket	3.57	1.28
Memobile	4.00	1.05
Anger Management	4.00	1.05
Personal Hygiene	2.44	1.13
Starting Work	4.00	1.05
Stress at work	4.11	1.05
Work Sustainability	4.25	1.03

Table 5.15. The speech used was clear and understandable

game	mean	STD
Cheese factory	3.29	0.61
My Appearance	3.25	0.75
3D Work Tour	3.58	0.90
VR Supermarket	3.43	1.16
Memobile	3.00	0.00
Anger Management	2.80	0.42
Personal Hygiene	3.22	0.67
Starting Work	3.00	0.00
Stress at work	3.00	0.50
Work Sustainability	3.00	0.00

Table 5.16. Failures were typically results of disorientation

game	mean	STD
Cheese factory	4.21	0.89
My Appearance	3.64	0.93
3D Work Tour	3.58	0.51
VR Supermarket	3.43	0.94
Memobile	3.36	0.84
Anger Management	3.40	0.97
Personal Hygiene	3.54	0.88
Starting Work	3.14	1.03
Stress at work	3.78	0.67
Work Sustainability	3.75	0.71

Table 5.17. Starting the software was an easy process

game	mean	STD
Cheese factory	4.86	0.36
My Appearance	4.43	1.09
3D Work Tour	4.25	1.14
VR Supermarket	4.36	0.63
Memobile	3.79	1.42
Anger Management	4.10	1.19
Personal Hygiene	4.08	0.76
Starting Work	4.08	1.14
Stress at work	4.11	1.27
Work Sustainability	3.88	1.25

Table 5.18. Closing the software/Quitting at the end of the game was easy

game	mean	STD
Cheese factory	4.86	0.36
My Appearance	4.36	0.63
3D Work Tour	4.08	0.67
VR Supermarket	4.21	0.80
Memobile	4.07	1.27
Anger Management	4.00	0.47
Personal Hygiene	4.46	0.66
Starting Work	4.00	0.68
Stress at work	4.00	0.50
Work Sustainability	4.13	0.64

Table 5.19. Quitting during the game was easy

game	mean	STD
Cheese factory	4.36	1.15
My Appearance	3.29	1.54
3D Work Tour	2.08	0.79
VR Supermarket	3.00	1.71
Memobile	2.07	1.49
Anger Management	2.20	0.79
Personal Hygiene	3.08	1.38
Starting Work	2.14	1.46
Stress at work	2.11	0.78
Work Sustainability	1.38	0.74

5.1.3.4. Questions concerning the graphics (10 questions)

Questions regarding the graphics:

Table 5.20. The software's look is realistic

game	mean	STD
Cheese factory	3.29	0.61
My Appearance	2.21	1.37
3D Work Tour	2.25	1.54
VR Supermarket	3.69	0.48
Memobile	3.07	0.99
Anger Management	3.70	1.06
Personal Hygiene	2.77	1.09
Starting Work	2.36	1.28
Stress at work	3.67	1.12
Work Sustainability	1.88	1.46

Table 5.21. The software's look is likeable

game	mean	STD
Cheese factory	4.07	0.73
My Appearance	2.79	1.63
3D Work Tour	2.25	1.36
VR Supermarket	3.85	0.89
Memobile	4.00	0.88
Anger Management	3.30	1.25
Personal Hygiene	2.54	1.13
Starting Work	3.21	1.12
Stress at work	3.22	1.09
Work Sustainability	1.75	1.39

Table 5.22. The software's look was appropriate to its aim

game	mean	STD
Cheese factory	3.92	1.21
My Appearance	3.86	0.53
3D Work Tour	3.83	0.58
VR Supermarket	3.93	1.14
Memobile	3.50	0.76
Anger Management	4.10	0.32
Personal Hygiene	3.15	0.69
Starting Work	3.64	0.74
Stress at work	3.78	0.44
Work Sustainability	3.88	0.35

Table 5.23. The pictures used were easy to recognize

game	mean	STD
Cheese factory	3.57	0.85
My Appearance	4.21	0.58
3D Work Tour	3.92	0.51
VR Supermarket	3.79	1.48
Memobile	3.93	0.62
Anger Management	4.20	0.42
Personal Hygiene	3.77	0.44
Starting Work	3.86	0.53
Stress at work	3.89	0.33
Work Sustainability	4.00	0.00

Table 5.24. The illustrations and backgrounds used were helpful

game	mean	STD
Cheese factory	3.50	0.65
My Appearance	3.79	0.97
3D Work Tour	3.00	0.00
VR Supermarket	3.00	1.30
Memobile	3.79	0.80
Anger Management	3.80	0.42
Personal Hygiene	2.00	1.35
Starting Work	3.07	0.47
Stress at work	3.11	0.33
Work Sustainability	3.00	0.00

Table 5.25. The connection between the pictures and the actions rendered to them were unambiguous

game	mean	STD
Cheese factory	3.29	0.83
My Appearance	3.71	0.91
3D Work Tour	3.25	0.62
VR Supermarket	3.07	0.62
Memobile	3.50	0.65
Anger Management	3.10	0.56
Personal Hygiene	3.15	0.55
Starting Work	3.36	0.63
Stress at work	3.11	0.60
Work Sustainability	3.13	0.35

Table 5.26. Failures were typically results of not being able to recognise pictures

game	mean	STD
Cheese factory	2.79	0.97
My Appearance	2.43	0.85
3D Work Tour	2.75	0.45
VR Supermarket	2.93	1.27
Memobile	2.36	0.74
Anger Management	3.20	0.42
Personal Hygiene	2.15	0.89
Starting Work	2.86	0.77
Stress at work	3.11	0.33
Work Sustainability	2.50	0.76

Table 5.27. Failures were typically results of not understanding instructions

game	mean	STD
Cheese factory	3.07	0.73
My Appearance	2.79	1.05
3D Work Tour	3.17	0.58
VR Supermarket	3.71	0.91
Memobile	2.79	0.97
Anger Management	3.20	0.63
Personal Hygiene	4.00	1.47
Starting Work	3.14	0.95
Stress at work	3.22	0.67
Work Sustainability	3.13	0.83

Table 5.28. The software was rich in (visual and audio) stimuli

game	mean	STD
Cheese factory	3.29	0.73
My Appearance	3.36	0.84
3D Work Tour	3.08	0.51
VR Supermarket	3.79	1.48
Memobile	3.07	0.62
Anger Management	4.00	0.47
Personal Hygiene	1.92	1.32
Starting Work	2.86	0.53
Stress at work	3.78	0.44
Work Sustainability	3.00	0.00

Table 5.29. The screens of the software were detailed

game	mean	STD
Cheese factory	3.93	0.73
My Appearance	3.21	0.97
3D Work Tour	3.18	0.60
VR Supermarket	3.79	0.69
Memobile	3.07	0.62
Anger Management	3.40	0.69
Personal Hygiene	3.69	0.75
Starting Work	2.93	0.79
Stress at work	3.22	0.44
Work Sustainability	3.00	0.00

After every question there is a “If you wish comment, why you have selected the given answer” open ended question to supplement the response given. At the end of the test there is a “30th question” - a half page for further notes, comments and remarks.

5.1.3.5. Score of user interface

Table 30 contains the mean of the scores written in Tables 1-29. All the scores are above 3.2 and 0.487<STD<0.803.

Table 5.30. Mean and standard deviation of the games’ total points

game	mean	STD
Cheese factory	3.754	0.752
My Appearance	3.522	0.593
3D Work Tour	3.255	0.638
VR Supermarket	3.644	0.547
Memobile	3.318	0.570
Anger Management	3.614	0.487
Personal Hygiene	3.360	0.736
Starting Work	3.232	0.504
Stress at work	3.521	0.525
Work Sustainability	3.203	0.803

In conclusion the scores show (>3.2); all the games’ user interfaces are user friendly and suitable for the target group, students with intellectual disability.

5.1.3.6. Design principles

We tested the following serious games: : “Cheese factory”, “My Appearance”, “3D Work Tour”, ”VR supermarket”, “Memobile”, “Anger management”, “Personal Hygiene”, “Starting Work”, “Stress at work” and “Work Sustainability” software. Our testing process is based on a 5-point Likert Scale. The test results show that we developed very “easy to use” and user-friendly games. Based on the evaluation results, we iterated our own design guidelines for serious games for use by people with intellectual and additional sensory impairments, which can currently be summarised as, [270], [22], [42,43]:

- Ensure presentation at appropriate speed
- Allow users to go back
- Allow User Control
- Make any text plain text
- Never convey information by colour alone
- Ensure sufficient contrast
- Help users navigate
- Make clear Maintain organisation
- Use unique and informative text descriptions for any hyperlinks (never click here!)
- Use accessibility features
- Design simply in simple layouts
- Use fallbacks
- Make systems consistent and error free
- Aim for compatibility with assistive technologies
- Allow keyboard access
- Do not include elements that are known to cause seizures

5.1.4 Conclusions of user interface evaluation of serious game

In this chapter I have discussed the design and evaluation of 10 serious games and their user interfaces. These serious games were developed for students with intellectual disabilities to help them in activities of daily living, their working life and specifically in managing a budget. We have demonstrated the test process of the user interface design of the serious games and our solutions for any identified problems for students with intellectual disabilities.

While many new technologies have become available for research and education, many fundamental problems remain to be addressed via informatics research. We hope that the number of investigations conducted in the field of serious games and Virtual Reality for special needs education will grow. Computer graphics are better now, and the 3D rendering techniques are becoming more mature, thus contributing to the reality of the simulated environments [19].

I have answered this topic's research question and I have developed a useful user questionnaire for testing serious games.

5.2 Introduction the design telemedicine system

Every year, more than 795,000 people in the United States have a stroke. About 610,000 of these are first or new strokes [271]. The number of strokes is set to rise because the proportion of Europeans over 70 is increasing. The projections indicate that between 2015 and 2035, overall, there will be a 34% increase in total number of stroke events in the European Union from 613,148 in 2015 to 819,771 in 2035 [272]. There are over 13.7 million new strokes each year [273]. Globally, one in four people over age 25 will have a stroke in their lifetime [274].

Many applications have been developed all over the world for stroke rehabilitation [65]. One of the most interesting of these researches is the VividGroup's Gesture Xtreme System.

[275,276] It is a unique approach to VR, which might have important applications for the rehabilitation of children and adults with physical and/or cognitive impairment.

Telemedically controlled systems, using low-cost, web-based audio-visual telemedicine units have been tested as well [277]. Connor et al. [278] in San Francisco used a haptic guided, error-free learning unit with an active force feedback joystick and computer for rehabilitation of cognitive impairments caused by stroke.

The project called “Virtual Reality for Brain Injury Rehabilitation”, developed at Lund University in Sweden, investigated usability issues of VR technology for people with brain injury; examined the issue of transfer and training; developed different applications of VR for training in daily tasks, such as kitchen work, using an automatic teller machine, finding one’s way in a complex environment, using virtual vending and automatic service machines. [279,280]

Questionnaires and focus group interviews were led in Sweden. The researchers addressed the question of usefulness of VR based rehabilitation equipment in practical therapy, by letting experienced therapists explore one such equipment for six months in their regular practice under natural circumstances. The conclusion was that such equipment has benefits beyond real life training, that variation in content and difficulty levels is a key quality for wide suitability and that the combination of challenging cognitive activities, which encourage motor training, was considered particularly useful [281].

According to Burke, the VR games were indeed usable and playable by people with stroke. Further, the games seemed to stimulate a high level of interest and enjoyment by the participants [282].

Older people and new technologies are principal research and development areas [283]. Improving the quality of life for elderly people is an emerging issue within our information society. Most of the stroke patients are in the older generations – their physical and emotional needs must be supported [284].

Within “StrokeBack” project, which was funded by the EU, the goal is to improve the speed and quality of stroke recovery [23], by the development of a telemedicine system which supports ambulant rehabilitation at home settings for stroke patients with minimal human intervention.

Changes in clinical practice cause that most patients are discharged from hospital within a very short time, so the research and development mostly concentrate on home-based rehabilitation. This approach has various advantages; for example, new skills are automatically transferred into daily life, improving motivation and morale. In addition, home-based therapy is less expensive, more motivating and, – because of the familiar environment – more comfortable too.

The recovery of the voluntary motor control is improved by many repetitions of functional exercises including fine finger and whole arm movements. By using serious games, patients are more motivated and willing to do more exercises. Moreover, these games mean not only recovery of sensory motor control, but improvement in logic and thinking abilities.

The aftercare of stroke patients was studied in a home-environment-based therapy system, through the StrokeBack framework [116]. Figure 5.1 shows the StrokeBack system.

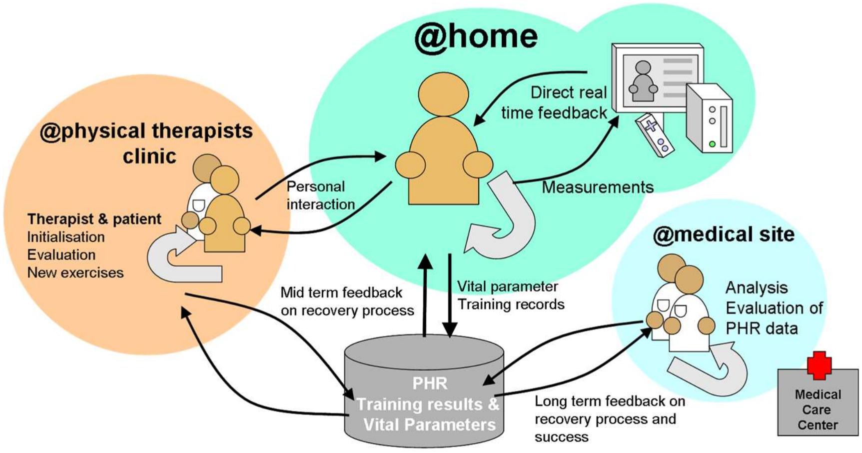


Figure 5.1. The StrokeBack rehabilitation cycle [116].

In the "StrokeBack" project I was assigned the task of leading the team at the University of Pannonia. The team members consisted of my students. The role of our team in the 'StrokeBack' project was to create serious games patients can use during their home rehabilitation process, or games that can replace clinical rehabilitation and speed up the process of recovery. The research questions regarding this study are what the functional and non-functional requirements of rehabilitation games are and whether traditional software development models can be applied to the development of telemedicine systems for stroke patients. In this chapter we focus on serious games and animations designed for the 'StrokeBack' project. The usability and special needs were in the focus of the development. In the development process we relied on our previous experience [3,22].

5.2.1. Wolf Motor Function Test

Jo [285] determined significant differences in Wolf Motor Function Test (WMFT) [286] score between before and after the intervention in the VR and control groups. Their study suggests that remote rehabilitation using functionally effective VR makes rehabilitation training an easy and pleasant experience for patients. Standen [287] showed a low cost virtual reality system for home based rehabilitation. Participants were assessed at baseline, 4 and 8 weeks using the WMFT and other tests of Daily Living [288]. The games showed in this chapter were developed based on WMFT test too. Success of the treatment relies then on the accuracy and repetition of the motor training. The games' controls in the 'StrokeBack' project were based on these single repetitive movements.

5.2.2. VR based games for StrokeBack project

In the first development pace the therapists said that games should be found out based on Wolf Motor Function Test (WMFT). For the assessment of different motion abilities WMFT uses series of tests consisting of 21 tasks. For the development of the rehabilitative game we received a variant of this test restricted for 11 tasks. For these motions, which are all plain motions, we planned different skill developing and arcade games. These games are shown in Table 5.311. In Table 5.31 there is a summary, which sums up, which of the particular games are appropriate for the practice of which test tasks.

Rehabilitation of stroke patients aided with games has a reason for existence.

In the StrokeBack project games are single player games, which the patient can play by himself/herself. After installing and setting up the software, the patient can use it alone; the therapist won't need to assist. This can be very convenient, because the user can play at any time, and won't need to wait for the appointment with the therapist. It is expected that the patients will play more with the games, than they would do exercises.

In the earlier phase of the development process Five games were under alpha testing: Wordy Labyrinth, Memory, Labyrinth, Word Puzzle and Free Kick. Out of the other two games, Break the Bricks, was already under beta-tests[44]. These games are not only aiming movement rehabilitation, but they can also improve mental condition with their easy logical puzzles.

Table 5.31. The connection of games designed for WMF test and the movement that can be practiced by them

Planned game	Break the bricks	FreeKick	Labyrinth	Memory game	Firework Game	Puzzle	Obstacle course	Pick your phone	Bunny-jump	Gardener game	Birdie game	Virtual piano	SUM
1. Other movements	x	x			x	x				x	x	x	7
2. Lift basket					x	x							2
3. Fold towel									x				1
4. Turn key in lock				x		x						x	3
5. Lift pencil								x					1
6.Lift can					x	x							2
7. Reach and retrieve		x			x	x	x			x			5
8.Extend elbow– weight				x	x	x	x						4
9. Extend elbow – side				x	x	x	x				x		5
10. Forearm to box													0
11. Forearm to table													0

5.2.2.1. Navigation in the games, controlling with events

The patient can navigate in the games' menu and start a selected game with dedicated hand movements, which are not used in the games. During the games, the patient can control the gameplay with specific rehabilitation exercises. The game is shown on the screen, and the icons for "pause", "help" and "quit the game" are shown on the interaction board. The patient can also stop the game with a dedicated stop movement.

The validations of the moves are very important, not only because it is harmful to learn a wrong movement. This is why not only the simple movement event is handled, but the features of the movements are connected to the different, predefined events.

This way the therapists can define sets of rehabilitation exercises which can be used and which fit for each game, so one game can be controlled with more different training movements. This is very good, because there is no need to make a new game for every exercise, and one exercise can be practiced with more games too, to make the patient more motivated and satisfied.

From another point of view, with these universal events, the therapist can set up the games to the patients capabilities. Because the real movement and the movement event is separated if the patient has lower range of motion, the movement tracking and validating device could be set up to a “lower level”, which evaluate more inaccurate movements as “good” ones.

Feedback

The foundation of a good gameplay is the player feedback. When the players’ input is matched with a response — whether it tells the player that they have hit or missed, failed or succeeded, or come close or far — the player remains involved in the exchange. The player is left disillusioned and uninterested if no feedback is given. This is why the feedback is crucial to any game. The satisfying player feedback can turn even the smallest success in a game feel fulfilling and can even keep players excited about something out of their control.

Feedback in the games can be provided in many forms. It is mainly connected to performance of the player and the accuracy of the rehabilitation exercise.

Performance feedback

A simple but informative feedback for the player is the reached score in the game. In our games, the score, the player achieved on a level is calculated from the time of completing the level, from the rate of accurate and inaccurate movements (determined by the “good” and “bad” markings in the movement events) and from specific parameters that each game has (for example in the Labyrinth the number the player hits a wall can be a parameter).

Another important feedback is the amount of time the player needed to finish a level. This is principally not important because of the speed, but because the patient needs to play at least for 5-7 minutes to practice a given exercise efficiently. If the player finishes a level too fast, then a harder level or a game with longer levels is needed for effective therapy.

It is important to mention, that these scores will not only be shown to the patient, but they are stored in the database of the game and sent to the therapist as a feedback about the patient’s performance.

5.2.3. Measuring the efficiency

The developer games are the most efficient if the patient enters into the spirit of the game. On the basis of the level of immersion the application gives different game experiences to the patients. The efficiency of the therapy — its expected efficiency based on indirect measurements — can be predicted. For this can the games’ user test be used, during which we examined — with volunteer stroke patients and therapists in clinical environment — that on which level could the users acquire the usage of the games. We also surveyed, with questionnaires, that on which extent did the game experience remain, and in what measure did the players find the games, serving a very serious rehabilitation method, a ‘playful’ one. After many phases of the development process, only three games were built into the StrokeBack system: The Break the Bricks (BTB) game, The Birdie game and the Gardener game.

"Break the Bricks" game

Break The Bricks game (Fig. 5.2) is a classic brick breaker game. It was very famous arcade game in the 90s. The goal of the game is very simple: smash the wall of bricks by deflecting a bouncing ball with a paddle (it could be a car, or a train, etc.). The aim of this game is to clear the screen by breaking the bricks appearing on the top of it. To break a brick, hit it with the ball several times.

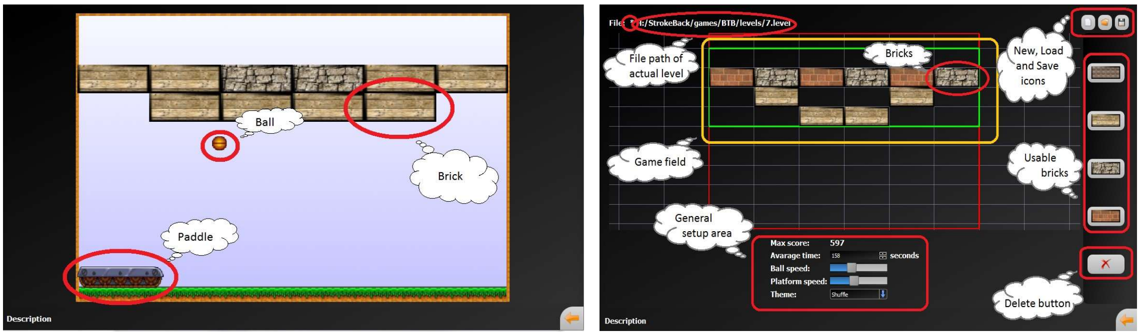


Figure 5.2. The Break the Bricks Game and the level editor for the game

The "Birdie" Game

In this game (Fig. 5.3) the aim of the player is to help a bird to get back home. The birdie is flying home, and the goal is to keep it in the air and prevent it from colliding with the obstacles, which can be other birds, rocks, trees, etc. If the bird bumps into something, the game will continue from the actual point, and the level won't restart. On the bottom of the screen a progress bar can be seen, which shows how much of the course is accomplished by the birdie, and how much is left.

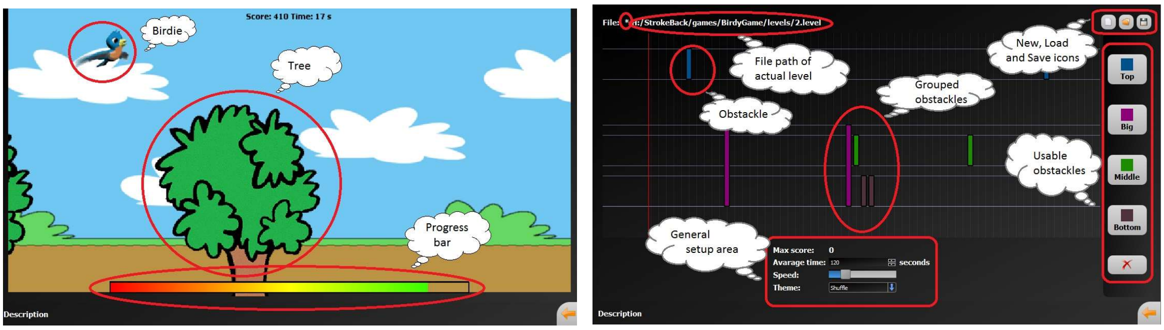


Figure 5.3. The Birdie Game and the level editor for the game

"Gardener" game

The task of the player in the Gardener game is to make the plants and flowers growing one by one. To grow a plant, the player has to water it several times with a dedicated movement . After a plant grows up, the player can continue with the next one till all of the flowers or plants in the garden are grown up. The status bar shows how many times does the actual plant has to be sprinkled until it becomes fully grown (Fig. 5.4). The count of these sprinkles is called "Required" motions.

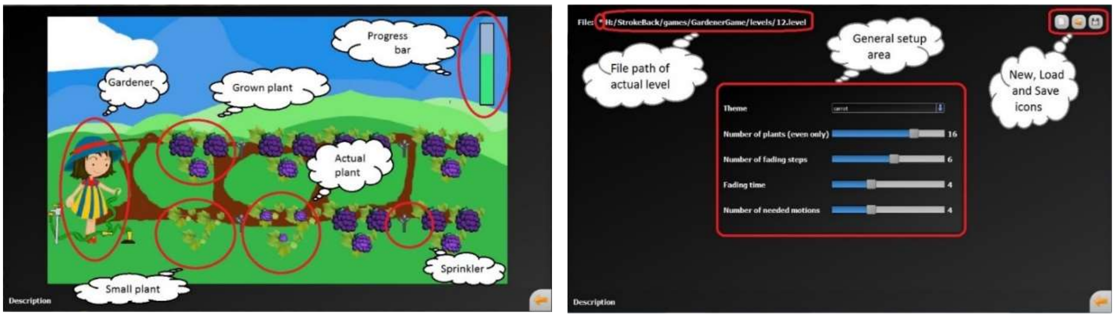


Figure 5.4. The Gardener Game and the level editor for the game

The tests have been carried out in two stages.

The first tests were carried out with a volunteer control group aged between 18-65, who were healthy and had no previous (professional) computer skills in this specific field. This group consisted of 35 persons. The first clinical test was carried out in the rehabilitation centre of Brandenburg Klinik. During the clinical test the games were tested by stroke patients older than 18. This group consisted of 10 persons, who were all stroke patients. Men were between 40 and 67 years old, women between 35 and 36 years old. The average age of men is 52 years, and the women's 35.5 years. The average age in the whole group was 48 years. The results of the two test series (the results of the tests for 'healthy' test subjects, and the results of tests for stroke patients) were compared after evaluation. Based on the answers we investigated whether the usage of the games were manageable and useable. The test subjects were asked about their subjective feelings of the games, and in the end of the tests, the test subjects were asked to form their own opinions concerning the games.

Questions for testing the games:

1. The loading of the games was not problematic.
2. I could easily acquire the usage of the game.
3. The game is understandable, easily usable.
4. The game was impulsive, amusing, I would like to play with it more.
5. The audio effects used during the game were disturbing for me.
6. The levels inside the games were getting hard too.
7. At the start and when I got stuck, I got enough help from the Users' Guide of the game.
8. The intermission of the game (pause, quit) was not problematic.
9. The appearance of the game is pleasing/ I like it.
10. The game, according to the feedback (game scores, time-check), is easily traceable.
11. I could easily manage the levels of the game.
12. Open questions for remarks and suggestions.

According to the answers on the questionnaire these developer games are applicable in the rehabilitation. On the basis of answers, concerning the usability and the difficulty of acquiring the games' usage, we found out that the usage does not serve any difficulties. 70% of the patients who filled the questionnaire have answered the questions. Among them, according to total calculation and averages 57,14% thought the usage of the game was easy, on a scale from 1 to 5 they classified them on the most positive 5th category; 28.57% classified them in the 4th category; and 14.28% classified them in the 3rd, medium category.

Table 5.32. Test results by the patients

Question:	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
BTB	4.63	4.73	4.77	3.53	1.03	1.87	4.10	3.93	4.07	4.30	4.20
Birdie	4.80	3.83	3.77	2.20	1.07	1.77	2.83	3.37	3.77	3.37	4.43
Gardener	4.67	4.07	4.00	2.07	0.80	1.87	2.27	3.30	4.00	2.90	4.60

Table 5.33. Test results by healthy control groups

Question:	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
BTB	5.00	5.00	5.00	3.33	1.44	0.00	0.00	0.00	4.33	4.11	0.00
Birdie	5.00	5.00	4.67	3.78	1.00	0.89	0.00	4.33	4.00	3.67	0.00
Gardener	5.00	5.00	5.00	2.44	0.22	1.00	0.00	3.33	4.44	4.44	0.00

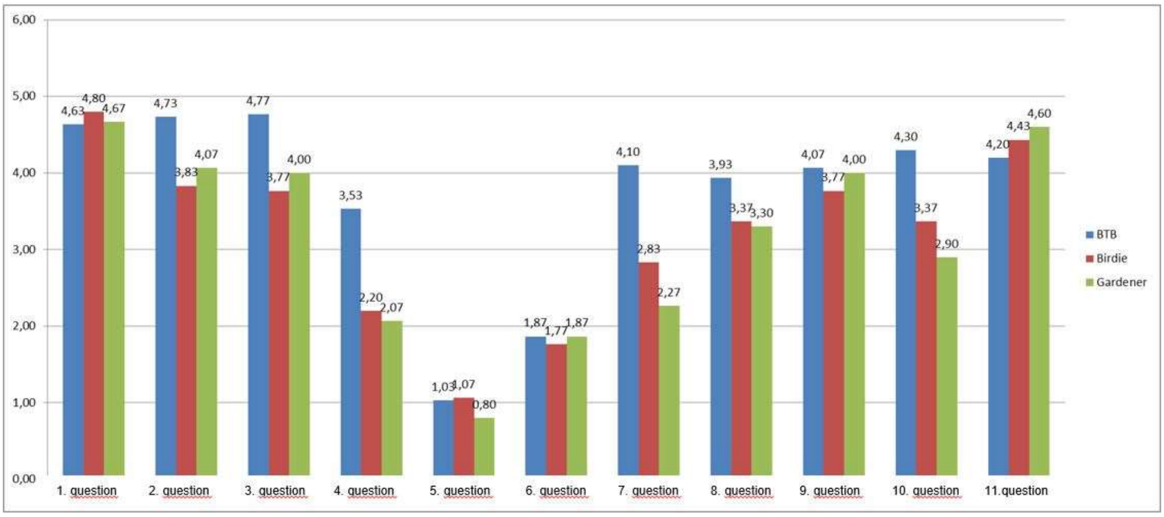


Figure 5.5. Test results by the patients

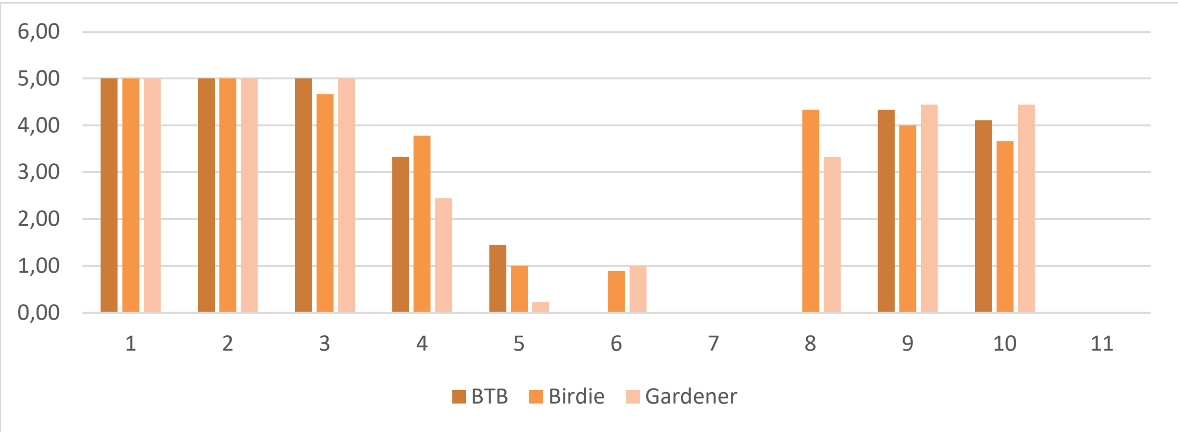


Figure 5.6. Test results by the health control group

The level of immersion determined whether the patients could show a better time in the completion of the games after fulfilling the levels from time-to-time repetition; whether they could beguile a longer time in the game, and rate the game less tedious. According to their freely expressed opinions, they were waiting the next difficulty levels of the games, they were curious about the next hardenings of the game levels; so the game experience, the feelings of competition and challenge fully remained, only one feedback contained such objection, which referred to the specific disease as an interfering factor of playing the games. These responses indicate that the computer game remains a computer game for the patient, where the primary goal is the physical rehabilitation, but during the testing they became the devices of relaxation for the patients.

This sequential exchange indirectly shows that the players — if they really enter to the spirit of the formed environment of the developer game — they will more efficiently use the game as a therapeutic tool. Based on the feedbacks the level of adoption exceeds our expectations. This is prior because if a new technology, no matter how efficient or focused it is, its usage will not show any results, if the target group cannot accommodate the new technology.

To sum up, the healthy control group was much more critical of the games in comparison with patients.

5.2.4. New software development method and specification of requirements

The traditional planning process always begins with the survey and specification of the requirements because the customer demands can define the development methodologies. To know which development method works the most efficiently for a certain project, the Structured System Analysis and Design Method (SSADM) offers efficiently applicable recommendations [289]. However, these were not appropriate for this project.

In parallel with software development, preceding the development steps, I made methodological examinations and researches and optimized the project tasks based on the available recommendations. According to these, during the exposition of the new methodology worked out. the critical points, where the planning and development process or parts of the process could not be built upon one or already exiting methodology, it became necessary to add new methods to the process because of the tasks and the customers' demands, needs. Also, besides the specialist and therapists who plan the rehabilitation, the developers using my new method cannot ignore the patients. The patients are not in the status of stockholders in the project, but they were the real stakeholders and target group of the complex software and hardware product to be developed. In Fig. 1, the general design process can be seen as during the game development process a relatively new software development method, Users' Focus In Needs&Development (UFIND) method was used.

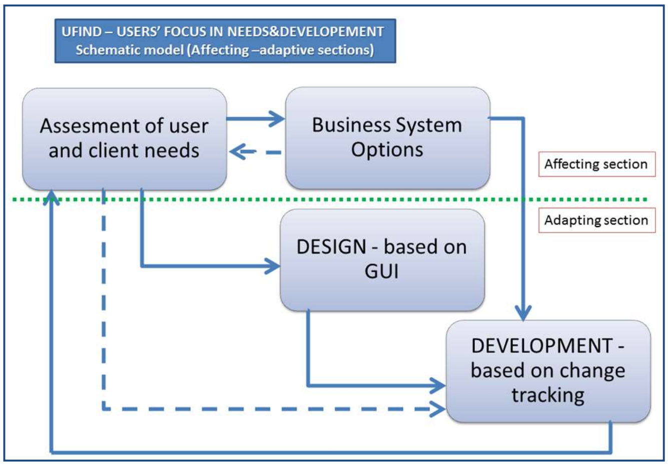


Figure 5.7. The UFIND method – schematic model.

The following subsections present the phases of the UFIND method (this method is under publication at the 11th IEEE International Conference on Cognitive InfoCommunications - CogInfoCom 2020 proceedings):

Step 1 – The investigation of current environment and the assessment of the user and client needs In Phase 1 the customers' and users' demands have been assessed and conciliated. There are three parts of these assessments:

- **Part 1**: The assessment of customers' claims
- **Part 2**: Surveying the needs of the users who are not in the same target groups as the customers (e.g. different social statuses, people with disabilities, etcetera)
- **Part 3**: Analysing of adaptation skills: The survey of the customers' claims did not cause any difficulty; the customer has outlined a concrete idea of a telemedicine perspective rehabilitation application that can be applicable in a home environment.

Remarks: In respect of the planned system, the examination of the IT skills of the healthcare staff was necessary. Above all, it should be assessed whether the staff will be able to efficiently use the rehabilitation program pack, will they be able to communicate with the patients appropriately about the topic, and how helpful will they be during the process of acceptance for the patients. It had to be surveyed that the patients how capable are of accepting a new technology, how much do they think the home environment personal computer supported therapy can be fitted into the traditional hospital aftercare process, how appropriate do they think the new system will help them in their recovery. All of these examinations took place on personal interviews. The following results were received: The peculiarity, which may have been observed during the survey of the demands was that the prospective users of the planned system, who are on one hand hygienic employees, on the other hand the stroke patients themselves, they were not able to express their actual expectations with the rehabilitative program in an informatics software development aspect (control, management, etc.). Most of the information was offered for the prospective relevant function, but that one also on a very special manner. The denial-rejection based drafting stood in the focus, which were composed according to comparing of other similar programs, for example not to have too small buttons in the menu, and other similar aspects. This carries a lot of information for us. Firstly, it makes a demand that concerns the manageability, but without numerical, actual data, to keep at the example relevant to the button's size in a graphic surface. Additionally, important information, which we were able to deduce from this and similarly expressed claims was that as a first step of the development, we have to accomplish the developing and implementation tasks connected to the graphic user interface. This fundamentally contradicts previous the software development methods applied until now, and strongly influences the development of the software's lifecycle. In the case of the SSADM, however, it is necessary to correlate the formed development method, because it organizes the whole development into one well documented process. The result of the first phase is a requirement-framework specification (on the basis of part 1 and part 2) and an adaptability study (on the basis of part 3).

Step 2 – Business system options Following Step 1, beyond the survey of claims and the definition of guidelines concerning the approximate requirements (not actual, concrete requirements!) the analysis of reception skills has been created. That latter one has the deciding role in the proceeding because if it shows complete rejection it is not worthy to do further analyses or to take unnecessary development steps. In this situation, the review of the customer claims is the expedient alternative, which the customer himself/herself has to accomplish according to the feedback then decide on the additional steps.

Step 3 – The gathering of requirements and the planning of graphic user interface According to most of the users, something is efficient, and the software is in development progress if its results can be seen. The plans of the planned program's graphic user interface have been created on the basis of users' demands. The plans of the interfaces belonging to the fundamental functions recorded in the requirement-framework specification have been created and implemented. From the beginning of the creation of the first graphic user interface, we have made early tests with the involvement of the user group.

These tests yielded results in the following directions:

- Based on the patient users' feedback we were able to ascertain about the GUI construction's applicability, perspicuity, and visibility,
- The therapist users also provided immediate feedback. According to the feedbacks, the functional and non-functional requirements started to outline, concretized. In this step, the planning documentations were made ready and as an output of the previous step, the requirement framework specification was completed.

Step 4 – Change-tracking based development This phase consists of two parts.

- Part 1: Modification of components, setting for changing needs
- Part 2: Planning and developing according to the new requirements As a result of the testing process of Step 3, new demands and requirements were concretized. In part 1, according to these needs, we adjusted the elements of the graphic interface. Besides the graphic interface, the further elements of the program have also been planned according to the functional requirements. In part 2, the plan and implementation of a communicational layer for the assurance of the system and its input devices' independence have been created.

Remarks: The following of the changes may have been the most important part of our work, because the system went through a lot of changes compared to the initial requirements. On one hand, the changes in the users' demands have been brought by the broadening scope of duties of the therapists connected with their own specialization, healthcare and therapy tasks. On the other hand, they were generated by the further options inherent in the already tested and shown program. As a result of this step, the logical plan, its models, the data link models, and its implementation for the database storing of results in the games with a therapeutic aim have been created. The output of this step is the completion of requirements documentation, the creation of new functions' development models, their implementation, and testing.

Step 5 – Modularization, migration, follow-up In the last phase of the development has been separated the framework program containing the rehabilitative games from the games. Between the steps of development, in this step, the optimization for the newly developed target hardware, the migration of interfaces related to the networking into the proprietary framework containing the rehabilitative games was done. Step 5 serves the opportunity for the following of further lifecycles of the finished application, and actions, if they are required.

5.2.4.1. Specification of requirements

During the research and development work, not only did I contact therapists, but patients with special needs and skills were also taken into consideration. Therefore, I have created a new software development method based on the needs of patients and therapists see above and I created the following Specification of Requirements:

- **Functional requirements:**
    - the evaluating framework should not be negative, make it motivational for the patient instead,
    - instructive animations may demonstrate all kinds of movement to be practiced prior to each game,
    - clear and straightforward feedback on the task and movement is needed,
    - let the user choose from different stories in the games,
    - a relevant motivational animation should be featured after each game,
    - make the game customisable with the help of a level editor.
- **Non-functional requirements:**
    - all games must run in an extendable framework,
    - the games should match each other in their structures and style,
    - the previously written elements may be used in the framework to avoid redundance.

5.2.5. Conclusion the design telemedicine system

This chapter described a number of games designed for the stroke rehabilitation. The main focus is on user interface and relevance feedback in the games, which were tested and with the help of them the efficiency and the level of immersion were measured. The games are adoptable for other type of rehabilitation processes. The clinical tests proved that the games are useful and user-friendly rehabilitation tools. The growing level of presence in the time of gaming increased the patients' activity, and it was a good foundation for using these serious games as a specific rehabilitation tool.

The games in the "StrokeBack" framework were all developed for therapy purposes. In the therapists' hands, all of the games become a device that amends the traditional therapy and gives the opportunity to practice movements dedicated for WMFT tasks. With the help of the level editor surface, the therapists have the opportunity to create a unique, personalized action program for each patient, which helps the therapists' work to a great extent.

The computer-aided healthcare-used programs amend, and after the learning process may even relay the presence of the healthcare professionals. The telemedicine system, besides kinesitherapy, accomplishes the aim to reach a greater self-dependence of the patients.

I have answered this topic's research question, stating that a new software development method is needed for the telemedicine system for stroke patients. Based on the results of chapter 5.1 and this chapter, I can formulate Subthesis III/1:

Subthesis III/1. I created the design requirements and testing methods of customisability concerning non-leisure multimedia and VR games for skills development and rehabilitation use. [2], [15], [18-24], [39], [44-53]

5.3 Creation and evaluation of a preoperative education website for hip and knee replacement patients

The use of websites to provide patient education is becoming more common. The benefits of a properly executed and effective preoperative patient educational intervention have been shown to result in improved psychological and physical well-being for patients undergoing surgery. The purpose of this pilot study was to determine the usability, utility, and feasibility of a website we created to increase engagement and improve the quality of the preoperative education patients receive in preparation for hip and knee arthroplasty. Eighty patients who met the inclusion criteria were recruited, aged between 40 to 65, among those 52.5% were female, 71.25% were placed for knee replacement, 28.75% for hip replacement. Forty patients were randomly assigned to paper education cohort, 40 to the paper and website education cohort. However, only 19 from each cohort participated in the survey questionnaire. The outcome of interest included qualitative data for patient knowledge, satisfaction, utilities, and usability, which were assessed based on the Perceived Health Website Usability Questionnaire online survey. The paper-based survey contains ten questions using a 7-point Likert scale while the web-based survey contains fourteen questions using the same 7-point Likert scale. Descriptive statistics and independent samples t-tests were used for comparative analysis of usual paper education and website education cohorts; whereby Microsoft Excel data analytics tool was used to compute the results. The Alpha level was set to 0.05 for the statistical results. The result of the study showed no statistically significant differences in both cohorts at the 0.05 level. We hypothesized that both information delivery methods were effective in increasing knowledge and engaging patients to their preoperative educations. According to the survey result for the nursing staff, the use of the website improved nursing workflow, efficiency, and patient education.

The research questions of this study are whether an accessible health-related website could be created based on my recommendations and how this website improves the nursing workflow, efficiency, and patient education. **HIII/2: Accessible health-related websites can be created based on my accessibility recommendations. These are useful for patients' education and improve the nursing workflow.**

5.3.1 Introduction the creation and evaluation of a preoperative education website for hip and knee replacement patients

It is estimated that 7 million Americans are currently living with hip or knee replacement, with the incidence of patients needing joint replacement skyrocketing. This will significantly impact the number of patients needing joint surgery education [290]. One study indicated the incidence of total joint surgery in the United States is now over 1 million procedures per year [291]. Knee and hip replacements are major operations that require tedious preparation to achieve a smooth process in the perioperative setting. As such, there is a growing need to deliver preoperative education to joint replacement patients. This is essential so that they can be aware of the requirements and obtain the knowledge they need prior to surgery. Likewise, surgical services and surgeons' offices are busy environments that fast track patients' preparation for surgery [292]. More specifically, orthopedic offices provide patient education through numerous means, such as e-mail, mails or letters, and short calls, to inform the patient about what to do and where to go, sometimes with minimal explanations.

Once these patients arrive in the preoperative centers, the nurses typically only spend 10 to 15 minutes to provide preoperative education to patients and families. This concludes with the patient leaving with a lot of preoperative documents, some of which are education-based. The process can be overwhelming, with the potential for causing anxiety [293]. Furthermore, the on-the-spot and quick preoperative education during the center visit does not allow patients time to absorb the information and ask relevant questions. To mitigate this problem, the creation of a preoperative education website for patients having hip and knee replacement is one way to educate patients and families at their convenience.

According to the literature, 74% of all U.S. adults utilize the Internet and 61% have looked for health or medical information on the Internet [294]. Accessing an online website prior to coming in to preoperative centers could allow patients to better obtain and absorb information. They would also be able to submit any questions they have while they are on the website and a preoperative team member could respond to their questions. Failing to fully address patient education needs could eventually become a patient safety issue. A systematic review of preoperative education for orthopedic patients showed a positive relationship between well-designed preoperative teachings and patients' anxiety and knowledge levels [295]. Other studies have also shown that preoperative education plays an important role in improving patient outcomes and satisfaction with their surgical experiences in the perioperative setting [296,297].

Many prior studies reported the benefits of web-based preoperative education. For example, one study reported that the web-based education program in busy preoperative care areas can improve surgical patient education [298]. Another study demonstrated increased knowledge achieved with internet-based education compared with face-to-face education provided by a nurse in an ambulatory orthopedic surgery center [299]. A randomized trial revealed higher knowledge levels in patients utilizing computer-based education compared to face-to-face teaching in the office, thus enhancing the delivery of care [300]. This mode of educating the patient must also be specific to the needs of a particular patient population [301].

In this research project, we sought to create and evaluate usability, utility, and feasibility of a preoperative website for the education of patients having hip and knee replacements in order to augment knowledge. The hope was that creating a preoperative education website, an informatics-based quality improvement innovation, would enhance the patient education care process. Web-based preoperative teaching can better incorporate evidence-based research into this important aspect of clinical practice and patient education.

5.3.2. Aim of the study

The purpose of this pilot study is to determine the usability, utility, and feasibility of a website created to improve the quality of the preoperative education patients receive in preparation for hip and knee replacement surgery. This was accomplished by: (1) gauging patient satisfaction on knowledge acquired with the typical paper education forms; (2) developing a preoperative education website; (3) evaluating the usability and utility of the preoperative education website; and (4) assessing the preoperative education website with regard to its feasibility to the host facility. As to feasibility, the question is: Does providing online education to patients preoperatively help nursing workflow and increase nursing efficiency? Augmenting patient preoperative education with computer-based teaching has been shown to allow for more time for direct patient care and pre-surgical preparation [300].

5.3.3. Usability, utility, and feasibility

Website usability can be defined as the extent to which a website provides what the end-user is trying to accomplish [302]. It has also been described simply as "user-friendliness" [303]. In the context of web-based education for knee and hip replacement patients, some of the things to consider with regard to usability include: making sure the screens are not too busy, looking at ensuring that the tasks to maneuver around the website are not multistep processes, and, lastly, whether it improves the patient's ability to seek and acquire their educational needs and does not make it more burdensome.

The concept of assessing utilization entails looking at how the patients perceived the benefits of preoperative education [304]. Did they feel that the website prepared them for surgery? Would they recommend it to a friend considering having arthroplasty surgery? Did the 24/7 available knowledge and links to nurse resources relieve some anxiety they had about the surgery? Knowledge deficit has been shown to be a possible contributor to anxiety prior to surgery [305]. In general, was it useful in providing a comprehensive single-source site for preoperative education, or did the patients feel they still had to go elsewhere to obtain instruction they felt they needed prior to surgery?

Some questions that would need to be answered in the affirmative from this study include: did the patients retain the information the same or better with the website versus the usual education methods such that there would be savings from decreasing the amount of paper to print the many learning materials? Was there increased adherence to family support planning and post-discharge instructions such that there would be a decrease in post-operative complications that would require readmission? Were less "live" nursing resources utilized for patient re-education such that nurses could now work more efficiently on other preoperative preparation? The benefits of a properly executed and effective preoperative patient educational intervention have been shown to result in improved psychological and physical well-being for patients undergoing surgery, leading to better outcomes [291].

5.3.4. Creation of the website

5.3.4.1. Choosing a website platform and name

In choosing a website format, the team considered many website creation software products and websites. The choices were narrowed down to WordPress© and Wix©. The ultimate choice was Wix© due to the ease of the manipulation and customization of the site's prebuilt templates. The company also provides Google analytics to users who purchase a domain name (or link their own to the site). The template design was chosen to be as simple as possible. This was felt to be important to obtaining data determining how many patients perused the site and may not considering the 50+ age group within which most hip or knee patients fall.

Our team designed and developed the website to ensure that the information was kept the same or similar to the education documents patients are presented with at their appointment in the Pre-Anesthesia Screening Services department (P.A.S.S.). A name was chosen for the site that could be easily remembered: www.jointsurgeryeducation.info/. Facility approval of the website was obtained before it went live.

5.3.4.2. Description and layout of the website

In designing the website, the team kept the menu buttons at the top of the page, since this was a scrolling website, which is a more modern website design. Literature has indicated that seniors prefer menu-driven button options to navigate a web portal versus serial navigation [306]. Serial navigation is when the next most important information only becomes available after clicking on the initial option, link or button [307]. The default scrolling design was difficult to alter in Wix©. Therefore, we provided links on the home page to PDFs for the documents that patients would receive in P.A.S.S. Links that open up another window work better than "buttons" directing users to a pop-up and is optimal for mobile devices [307]. As this study was intended to compare the same information provided to patients, creating PDFs of the scanned documents for menu links was necessary to provide this parity of information.

The front page of the website contained the most critical information for the patients, hence the reason the front page was allowed to remain in rolling format. A video from the education class that patients attend was linked on that front page, as well as required preoperative preparation activities. The location and what to do and where to go on the day of surgery are also on the website's front page. (A screen shot of a portion of the main page of the website can be found in Figure 5.8.)

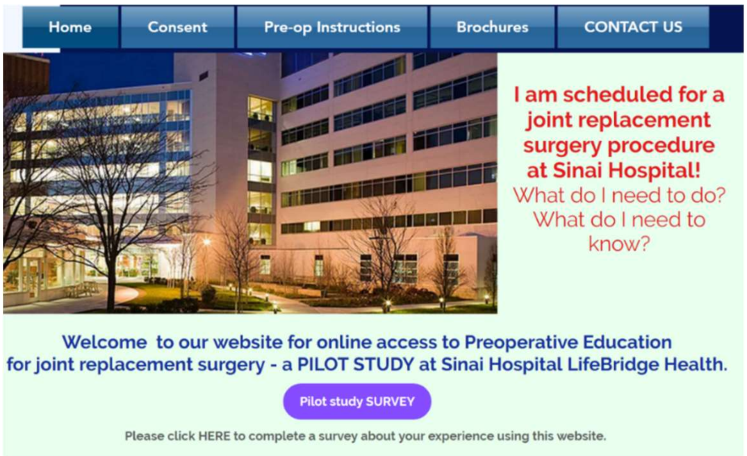


Figure 5.8. Screenshot of the Main Page of the Website.

5.3.4.3. Content of the website

The foundation and framework of the website content was based upon principles of patient empowerment through knowledge augmentation. The site contains preoperative information provided by one of the community hospitals in Maryland that follow anesthesia policies and protocol, orthopedic guidelines, and Joint Commission preoperative requirements for surgery. The website includes a checklist covering pre-operative testing requirements patients need to obtain before surgery. The checklist helps prevent delays and cancellations of surgery. It also lists fasting guidelines, medications to stop taking at least a week before surgery, things to bring on the day of surgery, and what to expect pre-operatively.

The website also includes videos about what to expect regarding joint replacement surgery and recovery. After viewing the videos, patients can ask questions via the site. These questions go directly to an email in-box for the P.A.S.S. nurses to answer. A phone number for the education class coordinator is available as another option for patients to call if questions arise after viewing the video. The brochures usually given by the community hospital in paper forms to patients during their preoperative visits (e.g., surgical site infections, fall prevention, anesthesia instructions, hand hygiene, MRSA infections, VRE infections, Sage wipes instructions, and nasal swab instructions) can be downloaded, printed, and shared directly on computers, tablets, mobile phones, using any modern web browser. Availability of these brochures on the Internet allows patients to read ahead of time and understand the importance of measures to prevent complications during and after surgery. Likewise, it is easier for the preoperative nurses to reinforce information in the brochure in a short period in the preoperative centers compared to giving these handouts during the visit and also conducting the educational teaching. On the main page, there are menu buttons to link to the informed consent, the purpose of the study, and biographies of the study team. The pilot survey questionnaires are embedded in the website and linked to Survey Monkey© for study purposes.

5.3.3. Materials and methods

5.3.3.1. Study settings, sample, and design

A prospective study was used to determine usability and utility of the online website, while a qualitative questionnaire was used to determine the feasibility aspect of the study. The study was conducted in a small community hospital in Baltimore, Maryland. The selected study sample was a convenience sample of two cohorts. The content of survey questionnaires was based on the Perceived Health Website Usability Questionnaire (PHWSUQ) for older adults [303].

The first cohort questionnaire was for patients who received the paper education in the preoperative center. The survey contained ten questions using a 7-point Likert scale (1 being Very Unsatisfied and 7 being Very Satisfied) assessing the following dimensions: satisfaction, ease of use, and utility [302]. The first three questions addressed the ease of use of paper educational material the patients received during preoperative visits. Questions 4–7 were about the degree of knowledge the patient acquired via the paper education as well as logic of organization of paper materials. Questions 8–10 asked about the usefulness of educational content in relation to decreasing patient anxiety and its utilization.

The second cohort survey questionnaire was for patients who accessed the preoperative website. The survey included fourteen questions utilizing the same 7-point Likert scale. The first five questions address the patients' satisfaction of the preoperative website. The sixth to tenth questions involve the usability of the website in patients' perspectives using a 7-point Likert scale (1 being Strongly Disagree to 7 being Strongly Agree). The rest of the questions measure the usefulness and utilization of the website information.

5.3.3.2. Data collection

The primary research investigators conducted data collection and analysis from December 2016 to March 2017 for both cohorts. The method of data collection for website usability and utility were patient questionnaires through Survey Monkey©. Inclusion and exclusion criteria were used as guidelines in the selection of study subjects. The inclusion criteria of the cohorts included patients who were scheduled to undergo their first or second hip or knee replacement, can speak English, were between the ages of 40 and 65 years old, had no mental or severe physical handicap, and had Internet access and an e-mail address.

The first cohort included those patients who would undergo hip and knee replacements with the same specified criteria and would show up in P.A.S.S. department for preoperative blood typing and screening. These patients received the usual preoperative educational pamphlets and face-to-face education by P.A.S.S. nurses. During the pilot study, the provision of preoperative education concluded with e-mail collection and verbal explanation of the purpose of e-mail request. These patients later received a survey link that took them to a Survey Monkey© questionnaire about the preoperative education documents they received on that day.

The second cohort included those patients meeting the same criteria who also received access to the preoperative education website. The primary investigator sent e-mails to patients who provided an e-mail address during the office visit. The e-mail contained a link to the website, instructions, and the purpose of the study. Additionally, the primary investigator called the patients the day before the appointments in P.A.S.S. to follow-up on the utilization of the website. The website guided patients to different sections for information and videos about their procedure, and a survey link was embedded into the website for patients to fill out before leaving the website. The website link distribution process also involved disseminating a pamphlet that contained web link as patient visited the P.A.S.S. department before surgery. The pamphlet served as a follow-up for those patients who did not access the website at home. At the end of data collection for both cohorts, survey questionnaires were distributed to nurses in the P.A.S.S. department to address the feasibility of the preoperative website for the education of hip and knee arthroplasty patients.

5.3.3.3. Ethical consideration

This pilot study is a quality improvement research project that meets the exemption criteria of organizational Institutional Review Board (IRB) with approval IRB #2400. The study protocols were submitted to the IRB board and met the IRB exemption criteria under 45 CFR 46.102(d), 21 CFR 50.3(c), and 21 CFR 56.102© as per institutional IRB review policies.

A short consent was embedded in each Survey Monkey© questionnaire informing the patients of the study purposes, that participation was voluntary, and reiterating anonymity in survey participation. No personal information was collected during the study, and patient e-mails were stored on an encrypted and password-protected computer onsite at the institution.

5.3.3.4. Description of cohorts

As noted in Table 5.34, a total of forty (n = 40) patients were selected to participate in the 1st cohort survey questionnaires. Twenty-two (n = 22) of these participants were female, and eighteen (n = 18) were males. Twenty-eight (28) of these participants were scheduled for knee replacement while twelve (12) were having hip replacement. Nineteen (n = 19) of these patients participated in completing the survey questionnaire, which gave us a response rate of 47.5%.

Forty (n = 40) participants were also selected to participate in the 2nd cohort survey questionnaire. Twenty (n = 20) of the participants were male, and the other twenty (n = 20) were female. Twenty-nine (n = 29) participants were scheduled for knee replacement, while eleven (n = 11) were having a hip replacement. Nineteen (n = 19) of the selected patients participated in completing the online survey available in the website.

Table 5.34. Descriptive Characteristics and Usability and Utility Statistics of Paper Education (Usual Care) and Website Enhanced Education (Intervention) Cohorts (n = 80).

	Paper Education – Cohort #1 (*n* = 40)	**Paper & Website Education – Cohort #2** (*n* = 40)
Age (years)		
40–49	6	8
50–59	15	15
60–65	19	17
Gender	**Frequency (%)**	**Frequency (%)**
Male	18 (45)	20 (50)
Female	22 (55)	20 (50)
Replacement	**Frequency (%)**	**Frequency (%)**
Knee	28 (70)	29 (72.5)
Hip	12 (30)	11 (27.5)

5.3.4. Data analysis and results

There are many ways to evaluate usability, such as heuristic evaluations, user testing in a lab setting and user surveys [303]. User survey was the chosen method for this study. For statistical analysis, Microsoft Excel data analytics tool was used to compute the results. The Alpha level was set to 0.05 for the statistical results.

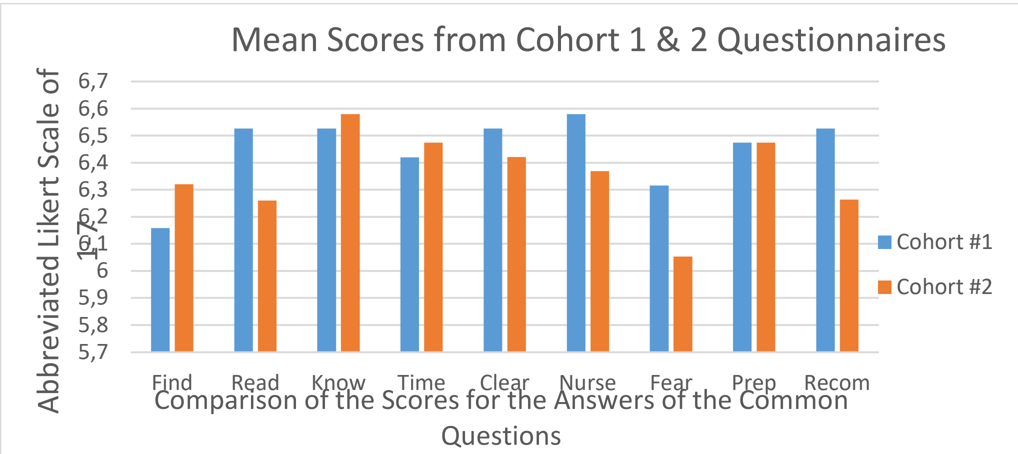


Figure 5.9. Bar graph displaying a comparison of the mean scores for the Cohorts.

As shown in Figure 5.9, patients' perceptions of the education via the website were higher in three areas: the ability to find information they needed for their preoperative education, the knowledge they felt they gained from being able to also view their preoperative information via a website, and the website cohort patients also gave higher scores with respect to the time it took to peruse the materials.

In the present study, there is no statistically significant difference between the overall average scores of the website users and those patients receiving paper documentation. Also, both methods of information delivery (e.g., paper vs. paper and website) were both effective methods in increasing knowledge and engaging patient in their preoperative education on any major joint surgeries.

5.3.4.1. Usability analysis

The usability of the new website was measured with the questions about how easy it was to find information, how easy it was to read it, how clear the information was, and the reasonableness of the time it took to peruse the site. The scores for how well the subjects felt that they could find specific information was higher for the website group, with a mean of 6.32 versus 6.16. The length of time that it took the study subjects to look over the materials via the website also received higher scores, 6.47 versus 6.42. These were the results when comparing the 9 questions in common for both cohorts.

When aggregating the grouping of the scores from the original 10 paper cohort questions and the original 14 questions from the website cohort's survey, we looked for any significant differences for usability. One question that required an answer in the negative (in order to reflect a "positive" response) was removed, as these researchers realized that many patients likely answered it inaccurately, and it would have erroneously skewed the results in a downward trend. So, 13 questions from the website cohort were analysed with independent samples t-tests for satisfaction, usability, and utility. In aggregate, the mean usability scores for the paper cohort is 6.48 and 6.35 for the web-based cohort, which was not statistically significant at the 0.05 level.

5.3.4.2. Utilization analysis

The questions on the utility of the website had to do with how much it helped with easing fear or anxiety about surgery, how helpful the information was at increasing knowledge about and preparing for surgery, how helpful it was to be able to contact a nurse, and how likely the patient was to recommend the site to someone else. In assessing whether the subjects would find the website helpful in preparing for use, questions 9 and 10 for the paper education and questions 13 and 14 for the website revealed higher scores for the paper cohort than the website.

In aggregate, the utility scores were 6.45 for paper education and 6.34 for web-based education. However, there is no statistical significance at the 0.05 level in terms of utility.

5.3.4.3. Knowledge

The subjects revealed scores of whether they increased in knowledge per question #4 for cohort one (mean 6.53) and question #6 for cohort two (mean 6.58). The website group scored their perceived knowledge increase higher. Although statistically insignificant, this is an important area of patient education to assess, as it indicates how much information the patient feels they received through the education provided. This is a critical quality indicator that has been linked to unanticipated post-surgical readmissions. The rate of surgical site infections is one of the patient safety indicators that healthcare regulators scrutinize. Education on how to prevent surgical site infections addresses this indicator. A website where the patients feel they have been provided superior knowledge on the subject of patient preparation for surgery, where, for instance, skin cleansing in preparation for a surgical wound is taught, are relevant to hospital quality statistics.

Additionally, education on anesthesia guidelines prior to surgery is relevant knowledge to prevent delays and cancellation of cases on the day of surgery. Preventing delays and cancellation of cases in the operating room is a financially-driven effort since it can affect Operating Room revenue as well as the organizational expense and ultimately patient costs. Preparation for surgery and knowledge of the upcoming procedure both scored higher for the website-enhanced education and this is a relevant factor for patient safety. This information in this pilot study is a promising sign for future studies as it shows that both delivery methods are satisfactory to patients.

5.3.4.4. Satisfaction

The scores regarding the subjects' feelings of satisfaction with the information provided on the website are also captured in questions 1–3 for cohort 1 (mean 6.44) and questions 1–5 for cohort 2 (mean 6.28). There was no statistically significant difference between the subjects' scores at the 0.05 level. The questions that were collecting common data for each cohort are presented in Table 5.35 and Figure 5.9. Table 5.36 provides the full data for questions presented to the subjects. The actual Survey Monkey© results, with the means and standard deviations for all questions to both cohorts, are also presented in Table 5.37.

Table 5.35. Questions common to both cohorts. Patient Evaluations on the Usability and Utility of the Website (showing the results of the independent samples t-test comparing only the nine "common" question items of the two cohorts).

Question Item ("Category name in Figure 2.")	Paper (n = 19) Mean (SD)	Website (n = 19) Mean (SD)	*t*-test *p*
1. Ease of finding specific information. ("Find")	6.16 (1.50)	6.32 (1.34)	0.74
2. Ease of reading the information given. ("Read")	6.53 (0.75)	6.26 (1.33)	0.47
3. Reading the documents helped me improve my knowledge about my upcoming procedure. ("Know")	6.53 (1.39)	6.58 (0.59)	0.88
4. I found the length of time needed to look over the materials/website appropriate. ("Time")	6.42 (1.43)	6.47 (0.50)	0.88
5. The content of the materials/website provide clear information. ("Clear")	6.53 (0.88)	6.42 (0.49)	0.66
6. I found information on how to contact the nurse for further questions helpful. ("Nurse")	6.58 (0.88)	6.37 (0.48)	0.38
7. The content reduced my fears/anxiety about surgery. ("Fear")	6.32 (1.03)	6.05 (0.89)	0.42
8. The content was useful in preparing me for surgery. ("Prep")	6.47 (1.04)	6.47 (0.50)	1
9. I would recommend the materials/website to other people. ("Recom")	6.53 (0.99)	6.26 (0.71)	0.37

Note. *T*-test significance for p = < 0.05.

Table 5.36. The Patient Cohort Questionnaires.

***Preoperative Preparation and Teaching Website - Perceived Usability Patient Survey Questions** for Total Arthroplasty Hip & Knee Patients*

*Adapted from: E.-S. Nahm et al. / Development and Pilot-Testing of the PHWSUQ for Older Adults

Questionnaire #1 (This was completed by the cohort who utilized usual P.A.S.S. education on PAPER.)

We would like to know your opinions about the **paper documentation** that you received for patient preparation and education on total knee and/or hip surgery (please circle your choice).

Satisfaction

1. Ease of finding specific information.

Very unsatisfied 1 2 3 4 5 6 7 Very satisfied

2. Ease of reading the information given.

Very unsatisfied 1 2 3 4 5 6 7 Very satisfied

3. Overall appearance of the pamphlets.

Very unsatisfied 1 2 3 4 5 6 7 Very satisfied

Ease of Reading

4. Reading the documents helped me improve my knowledge about my upcoming procedure.

Strongly disagree 1 2 3 4 5 6 7 Strongly agree

5. I found the length of time needed to look over the materials appropriate.

Strongly disagree 1 2 3 4 5 6 7 Strongly agree

6. The content of the materials provide clear information.

Strongly disagree	1	2	3	4	5	6	7	Strongly agree
Usefulness								
7. I found information on how to contact the nurse for further questions helpful.								
Strongly disagree	1	2	3	4	5	6	7	Strongly agree
8. The content of the preoperative education materials reduced my fears/anxiety about surgery.								
Strongly disagree	1	2	3	4	5	6	7	Strongly agree
9. The content of the preoperative education materials is very useful in preparing me for my surgery.								
Strongly disagree	1	2	3	4	5	6	7	Strongly agree
10. I would recommend these education materials to other people.								
Strongly disagree	1	2	3	4	5	6	7	Strongly agree

Table 5.37. Excel Spreadsheets Exported from Survey Monkey.©.

Mean and standard deviation of patients rating on the *PHWSUQ for each item on the scale (n=19)	
Item	**Mean (SD)**
1. Ease of finding specific information.	6.16 (1.50)
2. Ease of reading the information given.	6.53 (0.75)
3. Overall appearance of the pamphlets.	6.63 (0.67)
4. Reading the documents helped me improve my knowledge about my upcoming procedure.	6.53 (1.39)
5. I found the length of time needed to look over the materials appropriate.	6.42 (1.43)
6. The content of the materials provide clear information.	6.53 (0.88)
7. I found information on how to contact the nurse for further questions helpful.	6.58 (0.88)
8. The content of the preoperative education materials reduced my fears/anxiety about surgery.	6.32 (1.03)
9. The content of the preoperative education materials was useful in preparing me for my surgery.	6.47 (1.04)
10. I would recommend these education materials to other people.	6.53 (0.99)

5.3.4.5. Feasibility of the website to the P.A.S.S. Department

A qualitative feasibility study was conducted using a survey questionnaire distributed to the nurses in the P.A.S.S. department. In addressing this goal, the study team sought to determine whether the staff would experience a benefit to having the website, in terms of nursing efficiency and cost-containment, while delivering the same content of preoperative education. The objective of this assessment was also looking for whether the nurses felt that increasing accessibility of the education could have a positive impact on the patient. The survey contained five items asking direct questions answerable by yes or no. Provision for a comment section was available in each question. A total of thirteen (n = 13) nurses participated in the survey. The first question asked the nurses if the preoperative website for hip or knee replacement helped expedite the process of the preoperative education they provided to patient visits. All thirteen (n = 13) nurses answered in the positive. A few commented that the website allows the patient to receive information early and to think about it ahead of time. One nurse mentioned that if the patient understands the preoperative education ahead of time, it will save the nurse’s time in explaining the whole preoperative process and teaching.

The second question was about decreasing the amount of paper distributed to patients during the P.A.S.S. visit. Every participant's response was affirmative that preoperative website would decrease paper trail process.

The third question queried the nurses on the capability of the website to aid in re-enforcing patient education preoperatively versus the paper education alone. The entire group of participants agreed that the website could be a positive re-enforcement of preoperative education to patients. A few nurses remarked that the website allows the patient to read the materials in advance and reinforcement would be easier as they come to preoperative centers.

The fourth question asked the nurses if the website would help educate family members and caregivers of patients in a convenient way. All thirteen (n = 13) nurses agreed that the availability of the website is another medium for family and caregivers to learn about the patient surgery. The nurses commented that the department conducts a Joint Effort Class for two to three hours requiring patients, family members, and caregivers to attend. The online availability of the Joint Effort Class video allows the patient, family, and caregivers to learn about the patient surgery in a convenient and easier way versus arranging for coming onsite to the hospital for 2–3 hours.

The last question was about the relationship of the website's availability and adherence to family support. All participants in the survey agreed that the website could help increase the adherence of household support. Few participants commented that families or caregivers who cannot accompany the patient during their preoperative center visit would not be able to listen to the education provided by the nurses during the visit. However, with the availability of the website, the preoperative education could also be viewed by family members and caregivers at their convenience. Also, with the availability of interactive e-mails and phone numbers, caregivers' questions can be addressed in an easier way. Thus, family and caregivers can provide the support needed by the patient. Overall result, the nursing staff believed that the use of the website improved nursing workflow, efficiency, and patient education.

The full list of questions posed to the nurses can be found in Table 5.38 Table 5.39 shows the Nurse Survey Questionnaires on Feasibility.

Table 5.38. Nurse Survey Questionnaire and Data Table.

Nurse Survey Questionnaire
1. Do you think the availability of pre-operative website for hip and knee replacement patients' help expedite the process of preoperative education in P.A.S.S. department?
Yes:
No:
Comment:
2. Do you think the availability of the preoperative website for hip and knee replacement will decrease the amount of paper education provided to patients?
Yes:
No:
Comment:
3. Do you think that with the availability of preoperative website for hip and knee replacement will help re-enforced patient preoperative education when they come-in to P.A.S.S. unit versus the paper documentation alone?
Yes:
No:
Comment:
4. Do you think the preoperative website availability will help in educating family members and caregivers of patient in a convenient way?
Yes:
No:
Comment:
5. Do you think the preoperative website availability for hip and knee replacement will increase adherence of family support?
Yes:
No:
Comment:

Table 5.39. Nurse Survey Questionnaires on Feasibility.

	Total (*n* = 13)

Expedite nursing process (Y/N)	
Yes	13 (100%)
Decrease amount of paper education (Y/N)	
Yes	13 (100%)
Re-enforce education (Y/N)	
Yes	13 (100%)
Convenience to patient/family (Y/N)	
Yes	13 (100%)
Can increase adherence of family support (Y/N)	
Yes	13 (100%)

5.3.4.6. Accessibility testing

The last test was the accessibility testing.

The tests were performed by automatic checks using AChecker [121]. For the setting of the test, I have chosen WCAG 2.0 (level AAA). Figure 5.10 shows its results.

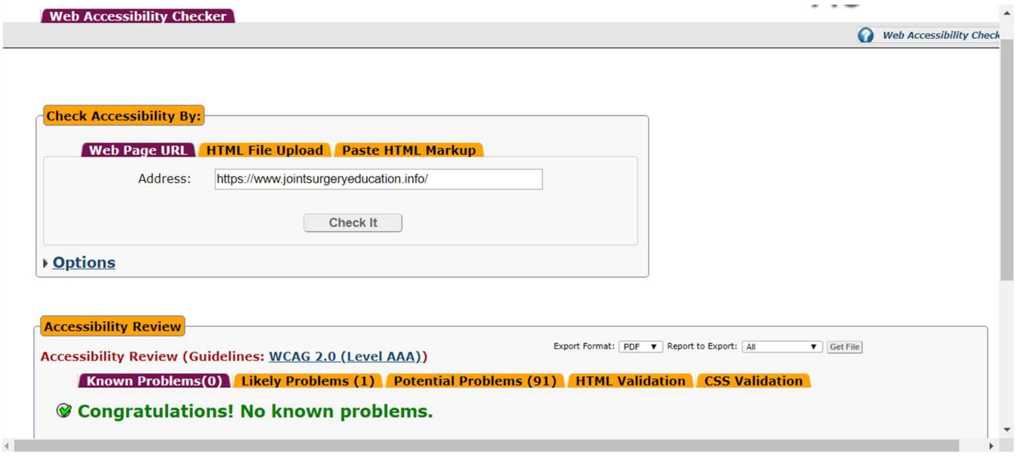


Figure 5.10. Screenshot of the AChecker automated tool (after the test, showing the results).

The AChecker did not find any "Known problems" at the strongest AAA conformance level. There is no doubt that the website was developed properly. It is easy to use and appropriate also for people with disabilities.

5.3.5. Discussion of the research and development the education website for patient

The ability to provide patients with a website to obtain preoperative education is an efficient way to provide timely evidence-based information to patients. As mentioned above, studies have shown positive outcomes and patient satisfaction from this form of education. [291], [296], [308], [309] As such, this study sought to expand this literature support to a local community hospital setting.

This being a pilot study, we were limited in having to utilize only the hospital approved education currently on hand. Thus, the creation of the website came with its challenges. It took a level of creativity to ensure that the structure of the website was as user-friendly as possible to the older adult population, while staying within the guidelines of providing the same or similar information that patients receive on paper.

Currently, the preoperative center allocated 10 to 15 minutes of preoperative teaching to each patient coming in for preoperative work up. However, the patient has to attend a separate Joint Effort Class that usually last for two to three hours excluding the waiting time in the registration area and the preoperative unit, and the travel time. Hence, clinicians need innovative methods to deliver an effective preoperative education.

Findings from this study suggest that it would be beneficial to patients, family, caregivers, and providers to use a preoperative website as an additional preoperative intervention to improve patient education. Findings showed that both participants who received the paper education during their preoperative center visit and those participants who utilized the website were satisfied with the preoperative content of both methods. This means that both methods of preoperative education are effective ways of education. However, in terms of accessibility and convenience for patients and caregivers, the online website provides an advantage compared to paper education. One study reported that a web-based education program in the busy preoperative care area is an effective way of improving preoperative education [298].

Given that this was a first-of-its-kind study at this facility, having patients evaluating a website, there was some coaxing in order to prompt them to fill out the survey. It is our belief that in their desire to be supportive to the P.A.S.S. department nurses, they may have felt the need to provide good marks on both the paper education and the website scoring. Of the paper education cohort, 57% of the cohort gave marks of all 7's (11 out of 19). For the website cohort, this number was only 26% (5 out of 19). This may be evidence of skewed results.

With regard to feasibility of website-based education for patients, the results from the pilot study found that although there was no statistical significance of the study interventions, the survey results showed patients utilizing the website rated their self-perceived increase in knowledge higher and had more satisfaction in the time to find and review the information. This is evidence of a significant positive impact on the value of patient preoperative education delivered via a website. The optimistic opinions of P.A.S.S. nurses about the website education further support the benefits of the preoperative website to the organization. This quality improvement initiative would still be feasible to more efficiently deliver preoperative education once a few changes could be made to the study plan, when moving forward with future additional studies. With those changes, the researchers will likely eventually see a favorable increase of website education utilization of patients in the implementation of web-based preoperative education to older adults in the facility.

In summary, patient evaluations of the website were affirming and nursing opinions were positive. In a future study, when researchers have additional time to analyse results, sections allowing for free-texting comments by the patients could be added. This would further assist in the patients developing more individualized website education to meet their needs. In general, however, it does not appear that there were any major usability problems with the website. The "contact us" link to ask a question of a P.A.S.S. nurse portion of the website was not utilized by any patients. However, in larger studies of website utilization in the future, such a link will likely be utilized more often by patients.

5.3.5.1. Limitations of the study

Given that this study was a convenience sample and utilized a small sample size, generalizability of findings is limited. Future studies should focus on replicating this study with larger and different surgery patient samples. Moreover, the primary investigator noticed that engaging the older populations to utilize the website requires a lot of effort to "market" it to patients. It will remain difficult to capture the majority of the patients scheduled for hip and knee replacement surgery unless it became a required part of consent for surgery, at the time of the decision to proceed with surgery. One study found non-usage to be an issue when study parameters provided that the patients self-direct themselves to a website [310]. This means that further study should be conducted about patient engagement, specifically for the older adults pending surgery, and website utilization.

This pilot study also only focused on knee and hip replacement patients and there is the possibility of comparing education via website for older patients having other surgeries. The result of that study can be used as a basis for creation and development of a preoperative websites in a more generalized area that includes all types of surgeries that are performed on older patients. That would require additional content and website development, unless the study could be conducted at different facilities that already have online website content, then the study could be targeted at obtaining data on the utilization of websites by older patients for preoperative education.

5.3.5.2. Opportunities for future research

Some other considerations to keep in mind for future studies might be additional evaluation of the patients who should participate in the study. We may want to include participants who have had surgery before (of any kind) with experience in receiving paper education in the past and also those who regularly utilize websites for healthcare education. This way we can better presume that our sample participants have had experience with both modes of learning. At the same time, we could also query additional questions such as the education level, household income, and employment status of the study types. Then lastly, it would also be helpful if we were able to pre-plan a longer lead time frame for the study to capture a larger population hip and knee surgery patients sooner to provide them the paper education first. In the study by Edward et al. [309], they captured almost 900 patients and provided preoperative education. Then, we could let time pass and then introduce them to the same education, but in the online format weeks or days prior to surgery. This would allow for paired sample survey testing.

5.3.6. Conclusion of the research and development the education website for patient

The results of this pilot study indicate that website-based delivery of preoperative education for major joint replacement surgery is feasible and has similar patient satisfaction compared to traditional paper-based methods. Further research is needed to determine whether website-based education can promote more efficient and higher quality outcomes for joint replacement surgery.

The result of this study verified the HIII/2 hypothesis, so I can formulate **Subthesis III/2.**

I have proved that accessible health-related websites can be created based on my accessibility recommendations. In addition, the use of such websites improves nursing workflow, efficiency, and patient education. [29]

Appendix A

Testing Methods of Colour-Fidelity and Barrier-Free Design of Virtual Worlds

The Theses Submitted for the

Doctoral Degree of the Hungarian Academy of Sciences (D.Sc.)

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Veszprém, 2020

I. Subject of the theses, previous research, main objectives, motivation

Developments in computer science, information technology and the available computing capacity have opened up new avenues for more realistic visual images. As a consequence, new disciplines, such as computer graphics and virtual reality, have been born. The question of colour-fidelity display is an exciting and challenging part of this process. One vital area of related research interest focuses on user demands and consequently on legitimasing the need for barrier-free designs thus, for instance, enabling people who are colourblind to freely obtain information.

With the appearance of the Internet the speed information has greatly increased, social networks and online gaming communities have appeared. This dimension encompasses millions of users. Social networks as well as online games can be understood as virtual worlds.

I have been engaged in two main research areas during the last two decades. The first area focuses on the topic of colour-fidelity display concerning computer software, the second on designing barrier-free applications. The two areas are closely related as minimum 10% of users tend to show a certain degree of impairment, a large propotion of it being visual in nature. [71] This observation necessitates the present Theses to have two different areas:

- one of them is the colour-fidelity of virtual reality-based games and designing colour correct web pages,
- the other one is the area of software ergonomics, especially barrier-free design so that anyone can easily use software or web pages. These can be either games or educational materials or health, medical IT rehabilitation applications.

Virtual Environment (VE): a synthetic, spatial (usually 3D) world seen from a first-person's perspective with real-time control of the user. In some literature, Virtual Reality (VR) and Virtual World are more or less synonymous with Virtual Environment (VE). [72] More specifically, VEs are distinguished from other simulator systems by their capacity to portray three-dimensional (3D) spatial information in a variety of modalities. They are able to exploit the user's natural input behaviours for human-computer interaction, and their potential to "immerse" the user in the virtual world. [68] The effects of human differences in immersive VR environments is a cutting edge research topic. [69] Inside this area, the colouristic features of small and large surfaces can be a new research topic validated by many real-life experiments and researches. [73,74]

More and more online three-dimensional (3D) games are to be found these days. According to Steinkuehler, the current global player populations of the most popular three games that she has studied over the past few years totals over 9.5 million – a population which rivals, e.g. most US metropolises. [75] However, there is an ever expanding gap between game heroes and the characteristics of real-life people. This difference is reflected in the choice of colours as well. Kids and youngsters are playing more and more VR games.

It was proven as an interesting hypothesis, whether the colorization of VR games has any influence on the users' memory colours. For this reason, I was aimed at studying the colourisation of different VR games, then I compared and contrasted the results with memory colours found in the scientific literature. [76,77]

The study of cultural differences has become an emerging field of research over the past decade. Cultural differences have an impact on human interaction with information. [78-80] In the last 1.5 decades I have been conducting researches on cultural differences concerning colour theory. It is widely known that colours may influence human emotions and feelings in the sense that some colours may make one happy, while some colours may evoke depression. [81]

Cross-culture studies indicate that different cultural groups show different responses and preferences to colours [82], and colour combinations [81,83].

Sato el al. [84] conducted surveys based on three characteristics: the influence of colours, chroma, and the relation of warm-cool colours. Smet et al. [85] carried out colour memory tests in different continents. It is clear to see from these few researches that colour test are often psychophysical experiments as well.

Multimedia applications often use graphical drawings instead of photographs because they can be more efficiently moved and stored. In many cases users regard pictures with fewer colours appropriate for use. In case of virtual reality (VR) simulations (most importantly those for purposes of therapy), a more realistic visualisation is required. Graphic designers – 3D modellers – have to choose from a great amount of hues representing qualities. Most multimedia programs enable a wide range of colours from their own palette but they do not provide adequate instructions as to how and where these colours are worth applying. Formerly, it was the task of graphical designers to colour pictures. Nowadays this task is being passed onto IT engineers – more frequently called animators – programming animations. Pictures have an aesthetic value as well, which means that the chosen colours cannot clash and that they have to be in harmony. There are several guiding principles regarding colour harmony. [86] When it comes to virtual museums, one could expect that paintings and other pieces on display are shown realistically.

Among the previous scientific researches, I must mention our multimedia-enhanced teaching resources as well. [1] One of the key areas of colour research is how users with some colour vision deficiency see software user interfaces and web pages. As populations expand, so does the number of people with colour vision deficiency. [87,88] This is not negligible as it means hundreds of millions of people. Therefore, when designing software, we must make sure that the colours used are harmonious and that the used colours are visible to a user with colour vision deficiency. In other words, they should be able to use the given software or website without problems.

The research in the field of barrier-free design has boosted recently. There is a growing number of publications and several important applications. Due to length restrictions, these will not be listed here [89,90] (apart from a collection of my publications) [2,3,30-33,55], and I would rather support the actuality and importance of barrier-free design based on data.

Among the priorities of the European Commission we can find the simplification of modern digital contract rules, the promotion of access to digital content, and the enhancement online sales. [91,92] They wish to support digital market strategies in the member countries. Moreover, they are introducing new e-commercial regulations in order to make buying and selling goods inside the EU easier. [93] In Hungary people made an online purchase more than 22 million times in 2015. [94] The retail turnover rate in Hungary grew by 18% in the first half of 2016, compared with the data from the previous year, and it reached 131 billion forints. [95] This number continues to grow. According to a survey of online sales with about 3,200 Hungarian webshops, domestic online retail reached a net annual turnover of HUF 425 billion in 2018, which is about 17% higher than the level in 2017 and 4.5% higher than the total Hungarian retail turnover. [96] According to the sector-level survey conducted for the seventh year, domestic online retail reached a gross annual turnover of HUF 625 billion in 2019, which was about 16% higher than the level in 2018. Online sales account for 6.3% of the total Hungarian retail turnover. [97]

Additionally, more than half of online shoppers have already purchased from a foreign web store. [98] Hungarian consumers have spent over HUF 145 billion in foreign web stores in 2019. [99] More than 50,000 new online shoppers have appeared within a month and a half at the start of the epidemic. [100]

WHO made the assessment that COVID-19 can be characterized as a pandemic on 11st March 2020. [101] We are not just looking at online commerce, but a much wider area of internet use. If we look at recent events, I mean, the pandemic caused by the COVID-19 virus, which made it necessary to stay home.

As the Covid-19 pandemic outbreak made working from home the norm for millions of workers in the EU and worldwide, a new analysis of the European Commissions's Joint Research Center (JRC) explores the challenges that countries, employers and workers are facing in adapting to the new work-from-home environment. [102,103] Millions and millions of people have been forced to work from home and learn from home, not to mention telemedicine. This situation and the need for home offices also support the importance of making the Internet accessible.

Most software engineering companies have not been developing produts for users with special needs because they do not see a potential market in these users. However, figures have proven that at least 10% of the world's population features some kind of impairment.[71] This number is estimated to reach 14% in the USA, and 65% of the population older than 65 years is to become handicapped. Disabilities correlate with age. In developed societies more and more people turning older than 75 are likely to have some kind of impairment. This group will comprise 14.4% of the population by 2040, compared with 7.5% in 2003 – it is almost a twofold increase. [104]

Another fact is that by 2020 25% of the EU's population will be over 65 years. Money spent on pensions, health and long-term care is expected to increase by 4-8% of the GDP in the forthcoming decades. These expenditures will triple by 2050. Let us not forget that the combined wealth of older Europeans is more than €3000 billion. [105] So if a company does not respond to launching barrier-free products, it is going to lose a great deal of potential customers/users.

New solutions are needed for the daily care and health monitoring of the elderly, who may not be able to move out of their homes [106], e.g. digital services for healthcare and social care at distance. [107]

Barrier-free Internet and software is an essential part of this process. It is not an easy task to make the Internet, software and VR applications barrier-free. The existence of the principles and standards of universal design/Design-for-All is not everything. [70,89,90] The regulations for a barrier-free Internet also seem inadequate. [108,109] The question is more complex if users' special needs are also being taken into account. The reason why I have done much research is to compile a list of minimum requirements that should be considered by all software engineers and computer specialists for developing the newest software and websites. [2,3,30-33,55]

Global augmented reality (AR) and virtual reality (VR) market is estimated to generate a revenue of USD 22.1 billion in 2020 and is expected to reach USD 161.1 billion by 2025, witnessing 48.8% Compound Annual Growth Rate (CAGR) during the forecast period. The market is driven by the factors such as increasing responsiveness about this technology, rapid acceptance of AR and VR technology among various industry domains and the amalgamation of AR and VR to develop the mixed reality that can be implemented for prospective applications. [110] Economic analysts of Virtual Reality and Augmented Reality (VR/AR) estimate a growth by USD 182 billion in the next 10 years. It is made up of USD 110 billion from hardware and USD 72 billion from software. [111] The leading software companies, e.g. Microsoft, are more reactive to developing barrier-free software thus there is a growing need for barrier-free design in the game industry as well.

To sum it up, as far as demographic figures are concerned, the users' demands, and the e-commercial and e-health endeavours, we can see how inevitable are the barrier-free softwares and Internet accessibility. In addition to all this comes the importance of colour fidelity as well. [5-8]

The aim of the present Theses is to put forward solutions to the highlighted barriers and issues based on measurements and statistical analyses and to find answers to the users' demands in order to provide them a higher standard of living. It offers testing methods, user-friendly solutions for colour-fidelity and accessible Internet and software designs.

II. Applied research methodology

The results summarised in my theses have been acquired by using the methods conventionally recognised by a narrower area of specialisation. During my research I concentrated on objective tests and measurements whenever I could. Visual-psychophysical experiments can be carried out with the application of different psychophysical methods. The experiments concerning colour theory are, on one hand, based on objective methods of measurement such as:

- the use of the Eyedrop tool of Photoshop,
- the application of a measuring instrument: X-rite Eye-One (i1), Minolta, Spectrascan spectrocolorimeter,
- test software developed by my student research team,
- Microsoft Excel data analytics,
- statistical program package R (R version 3.5.0.).

On the other hand, the colour memory tests are based on subjective psychophysical measurement.

As for the fields of Human-Computer Interaction and software ergonomics, I took measurements looking into barrier-free design firstly by: objective methods, the test software developed by my research team, and an international validation software; secondly, with the assistance of my research team I carried out surveys on the user interface and usability of games.

I put a great emphasis on how to universalise and scientifically comprehend the typically empirical data and results produced during my research via application or experiment.

In addition to the basic statistical calculations of the data gained by questionnaires, the equality of the ratios of the websites satisfying certain conditions was investigated. The correlation of error characteristics with country characteristics (e.g., elderly population ratio) was examined. The correlation of error numbers found by each testing program using the Pearson correlation coefficient was also examined. The hypothesis H0 was confirmed with a value of zero as the independence of the variables is true in terms of their Gauss distribution. The tests show that there is no correlation between the results of the tested test types, which shows that each validator software indicates different types of errors. Finally, clusters were made from the countries to investigate similarity in groups. For this purpose, the generally accepted k-means clustering algorithm was applied. All statistical computations were made by the statistical program package R (R version 3.5.0.).

I have given a thorough description of the projects involving international cooperation, laboratory experiments, and methods and questionnaires made for educational and rehabilitational observation in the publications indicated among my Theses. One of my main objectives was highlighting how and to what extent software ergonomical principles may be introduced in everyday software design practices.

Since I obtained my Ph.D. the Theses have been completed by new research and new findings. Apart from few publications on the results of our collaborative work with Professor János Schanda, most of the publications feature my collaboration and work as supervisor in connection with B.S.c and M.Sc. students and in one case a PhD candidate. All contributors and co-authors are indicated in the present research.

Particular theses include these publications in a more or less chronological order. I have listed 70 selected original publications (due to length restrictions) produced over the past 1.5 decades, however, there have been several other writings that demonstrate the validity of my hypotheses. (The unlisted publications are available online at MTMT.)

III. Summary of the new scientific results in theses

The Theses features a brief summary of my applied research outcomes. I differentiate between my theses as follows:

<u>First group of theses, in the field of colour design:</u> Virtual worlds are not displayed with realistic colours (i.e. closely resemble real object colours) even in such cases when the colour fidelity display, which affects our memory colours, would be expected.

<u>Subthesis I/1</u>. According to the tests, I have found that cartoon artists and VR game developers use unrealistic colours. [9], [34], [56-59]

I have collected more than 300 graphic pictures for the experiments, chiefly from cartoons from all over the world. Upon collection all pictures have been categorised. Almost every picture has a protagonist who has got a face, hair (blonde, brown, black or ginger). There are many landscapes (in case of pictures from Europe and Japan), so it is possible to examine the colours of the sky, clouds, ponds, grass, foliage, tree-trunks and sand.

Having completed the categorisation and determining the characteristics to be examined, a relational database was made to store the data. I stored all the important data that could be needed during the assessment. I also differentiated between the places featured in the pictures: landscapes, interiors, cities, portraits, etc. I used the CIELAB colour space for my measurements. [112] In contrast to the RGB and CMYK systems, CIELAB is a device-independent method of colour depiction, which is an international standard. [113] The CIELAB colour space is appropriate for illustrating all colours. This is why it has become the basis of transferring colour information. Besides lightness (L), in the CIELAB model you have to define chroma (C_{ab*}), which determine the balance between green and red, and blue and yellow. Colours can be categorised based on three characteristics: lightness, chroma, and hue. The colours of printed cartoons were analysed with a manual spectrocolorimeter. Settings: D65 CIE Illuminant and 2-degree standard observer. Online pictures were examined in Adobe Photoshop using the 'Sample Tool' feature then these data were stored in the database. According to the measurements, I have found the following:

I/1.1. In Japanese cartoons prepared for Internet presentation, stronger and more saturated colours are used, sometimes with lower lightness. In Europe, paler colours are preferred. This is true for most objects, except for complexion, where the Japanese use the palest colours, however, hue angle is larger than the one found in European complexion colours.

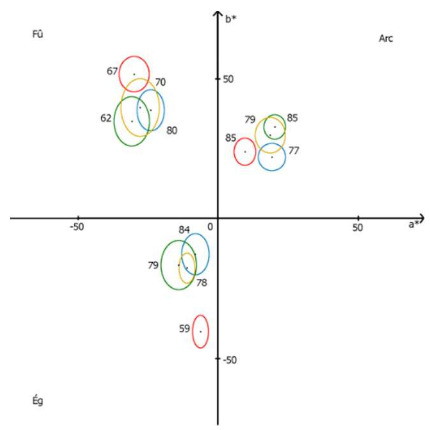


Figure 1: Typical complexion, grass and sky CIELAB values, depicted on an a, b* diagram. L* values are written in the vicinity of the standard deviation ellipses, shown in blue for American, in green for Australian, in red for Japanese and in yellow for European soft-copy cartoons.*

I/1.2. The present visulaisation demonstrates a different results in the case of printed cartoons. In print, the Japanese use paler colours, and the most vivid colours are found in Australian pictures.

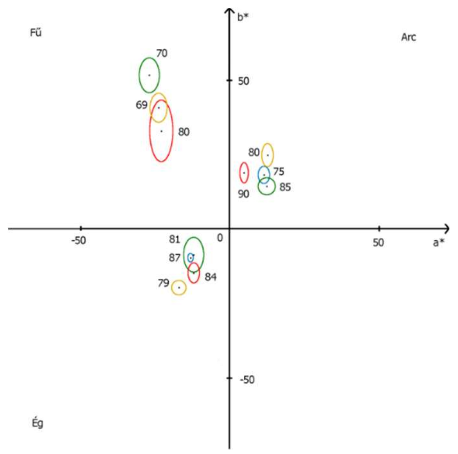


Figure 2: Typical complexion, grass and sky CIELAB values, depicted on an a, b* diagram. L* values are written in the vicinity of the standard deviation ellipses, shown in blue for American, in green for Australian, in red for Japanese and in yellow for European soft-copy cartoons.*

I/1.3. American cartoon artists do not often try to use colours that resemble those of real-life objects (bluish-green complexion, yellowish landscape).

I/1.4. Nevertheless, printed cartoons do not follow the above pattern. In print, the Japanese use paler colours, and the most vivid colours are found in the Australian pictures. American cartoon artists do not often try to use colours that resemble those of real-life objects.

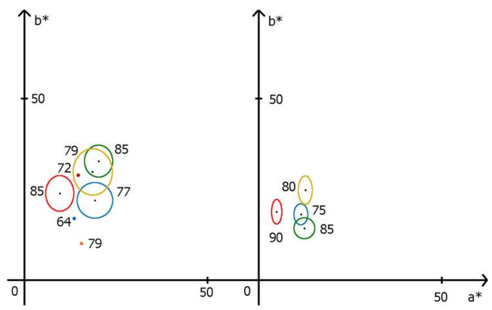


Figure 3: The colour of complexions depicted on an a, b* diagram. On the left, we can find the soft-copy (digital source), and on the right side, the hard-copy (pinted) results are to be found. The standard deviation ellipses are shown in blue for American, in green for Australian, in red for Japanese and in yellow for European. Orange spot: Bartleson [114], claret spot: Tarczali [115], blue spot: the average measured with tools. The nucleus is the average, the radius is the value of a*, b*, and the value of L* is indicated next to the ellipses.*

When analysing the colours of virtual games (with regard to their style, content, and graphics), I classified the most stylish ones. I divided them into 8 groups: (1) Action, Adventure and Mystery Games, (2) Children's Games, (3) Driving & Racing Games, (4) First-Person Shooting Games, (5) Simulation Games, (6) Role-Play Games, (7) Strategy Games, (8) Sports Games. I collected 752 pictures overall from 7-10 games per group. Then, I collected 179 pictures from particular films that had available game adaptations. Subsequently, I stored them in separate folders with source markings. I defined the colour traits of objects (e.g. trees, grass, foliage, sky, etc.) and beings (skin and hair colour of the game characters) that were seen in the pictures with the use of Adobe Photoshop. Then, I stored them in a database. I had a number of over 4,500 measurement data. I statistically analysed the database (average and standard deviation), and compared the results with the typical colours used in cartoons, and with our memory colours. I took the measurements in the CIELAB colour space. Visual differences between pairs of colours are indicated with marks (big, small, etc.). The CIELAB equivalents of this are defined by the difference of lightness and coordinates $a*$ and $b*$: Δh_{ab} hue angle difference (h_{ab} = arctan ($b*/a*$)) and ΔC^*_{ab} chroma diffrence ($C^*_{ab} = (a^{*2} + b^{*2})^{1/2}$). Following all measurements and calculations I managed to set up the following theses:

I/1.5. The colour of the complexion in VR games is yellower than in case of memory colours, the Action, Adventure and Mystery Games, Driving and Racing Games; yet when it comes to First-Person Shooting Games, they used brownish complexions even in case of characters of caucasian race. They used more realistic complexions in Children's Games, Simulation Games and Strategy Games.

I/1.6. The creators of VR games used unrealistic colours for colouring grass in this case as well. When it comes to films, Action, Adventure, and Mystery Games show a darker and browner colour of grass than our memory colours.

I/1.7. The colour of the sky in VR games concerning Action, Adventure, and Mystery Games; in First-Person Shooting Games, the colour of the sky is very grey. Films usually feature skies of lighter colours than their matching games. Action, Adventure, and Mystery Games include an almost white sky, while First-Person Shooting Games have a purple tone.

Subthesis I/2. The unrealistic colours of VR worlds influence our memory colours. The memory colour of the intellectually disabled students, non-gaming students, and VR addicts are different. [9], [35]

The notion of memory colour is used to describe the colours of such well-known objects that make us recollect some kind of past visual experience. One has to distinguish between memory colour and colour memory. The latter is the colour we will reproduce after we have seen a coloured object. Memory colours are well-stabilised products of our memory. They are colours we will pick from a high number of colour chips if one is asked to show the colour chip resembling the colour of human complexion, or sky blue, etc. A test software was implemented for this research. The observants had to colour black and white pictures using the stest oftware made by my student research team.

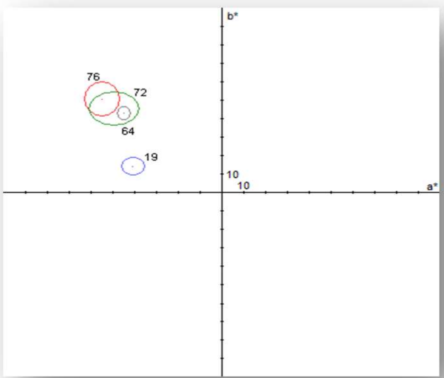


Figure 4: The result of the memory colour of grass, primary school children (red) L=76, children with intellectual disability (green) L*=72, game-addict university students (blue) L*=19, non-addict university students who rarely or never play VR games (grey) L*=64*

75 observers used this test software in 4 groups: 20 average elementary school children (aged: 8-9 years), 10 children with intellectual disability (age: 9-15), 24 virtual game addict university students (average age: 20) and 21 university students who rarely or never play VR games (average age: 20). The task was colouring pictures using the colour palettes inserted in the test software and answering a number of questions. The experiment was conducted in a dark room using a laptop computer, the monitor of which was calibrated by an Eye-One apparatus. Every observer had good colour vision, we tested them with Colourlite Colour Test. The chosen colours were stored in a database and later used for generating numeric data.

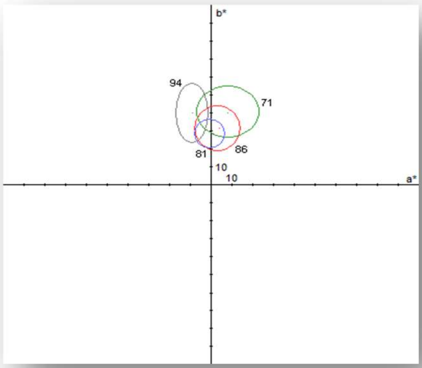


Figure 5: The result of memory Caucasian face skin, average elementary school children (red) L=86, children with intellectual disability (green) L*=71, game addict university students (blue) L*=81, university students who play VR games rarely or never (grey) L*=94*

Second group of theses, in the field of Human-Computer Interaction and WEB-accssibility: I research barrier-free design. I made recommendations to these concerning design and testing methodology. [10], [11], [12], [13], [14], [30], [31], [36], [66]

Subthesis II/1. I proposed a method for the colour-correct design of WEB and VR games so that people with colour deficiencies will not lose information and gain accessibilty. [15], [16], [40], [41], [57], [58]

I did not find any publications that would deal with the testing of colours of rehabilitation games. Therefore, I carried out the colourimetric testing of rehabilitation games designed for the “StrokeBack” project. [116] In this testing the main objective of the investigation was to find out how people with different colour-blindness types can perceive the games. For the investigation 4 different colour-blindness simulators were used. These are available on the Internet with picture uploading features (ASP.NET) [119], (ETRE) [117], (Coblis) [118]. Furthermore, the downloadable version of software ColorOracle (ColorOracle) [120] was implemented to test the pictures appearing on the screen on the developer computer. The aim here was to find out how the users of different types of colour-blindness – i.e. deuteranopia, protanopia, tritanopia – see the colours. As a result, I reached to the conclusion that based on correct colour design the objects are clearly visible, so colour-blind patients can practice the same way as people without visual impairment.

I made the colorimetric testing of the websites of Hungarian universities in the second research belonging to the thesis. The main purpose of this research was to answer the research question whether the websites of the Hungarian universities are accessible for those students who have some colour deficiency problems.

Three types of investigation were performed:

- automatic tests with AChecker [121],

- semi-automatic tests: five different colour-blindness simulators were used: ASP.NET [119], ETRE [117], Coblis[118] and ColorOracle [120]; these tested the pictures appearing on the screen on the developers' computer to find out how the users of different types of colour-blindness perceived the colours. The fifth one was the SEE [122] web-application.
- human tests with Variantor [123] special glasses and using questionnaires.

I determined the most common accessibility problems from the colour check point of view on 64 Hungarian University websites. Table 1 contains the number of known problems based on WCAG 2.0 [109] guidelines. The highlighted problems are in close connection with the visibility of websites.

Table 1: Number of known problems by WCAG 2.0 using AChecker

Guidelines	Levels of conformance	summa number	largest number	average number
1.1.1 Non-text Content	(Level A)	994	315	15.53
1.4.1 Use of Colour	(Level A)	2	1	0.03
1.4.4 Resize text	(Level AA)	579	77	9.05
1.4.6 Contrast (Enhanced)	(Level AAA)	2164	440	33.81

Fig. 6 demonstrates a design mistake: confusing colours. "Információk a 2016-/2017 tavaszi félévi államvizsgáról és diplomavédésről…" in purple in the right side of a black and white crest is very similar to the blue colour of the links despite the fact that it is not a link. This light purple is the same purple as the background of the main menu line and the colour of the submenu text below it. Fig 7 shows how confusing it is that the "Információk a 2016-/2017 tavaszi félévi államvizsgáról és diplomavédésről…" looks like a link, although it is not a link.

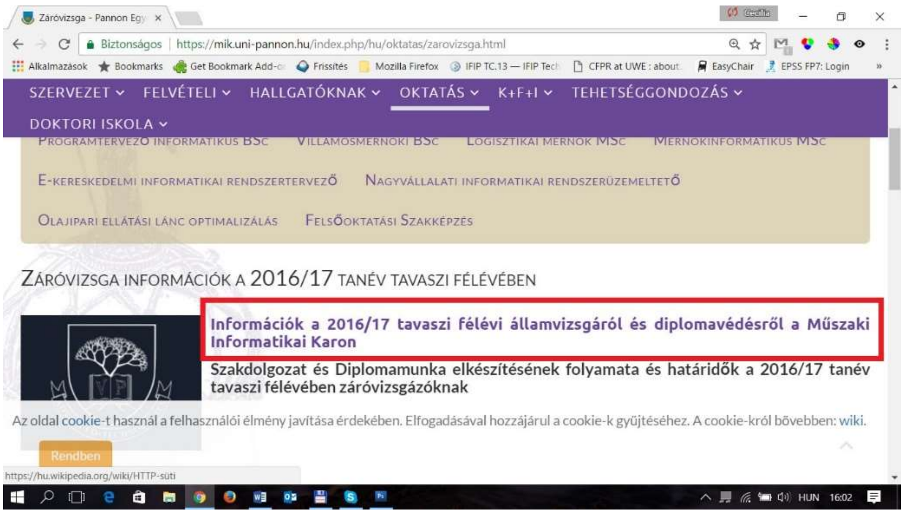


Figure 6: The original webpage of the information of the "final exam" site

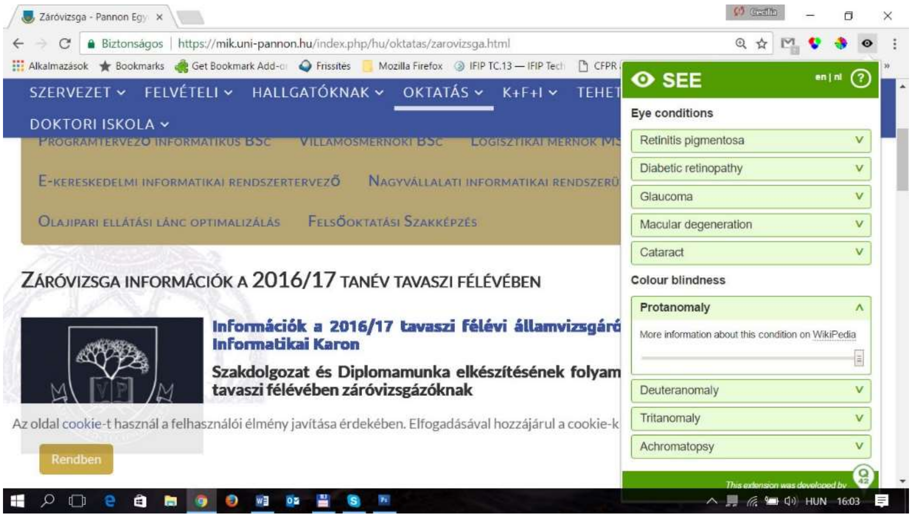


Figure 7: The webpage of the information of the "final exam" site as it is seen by a colour deficient user with protanomaly

The results of the tests and evaluations point to the conclusion that unfortunately not every Hungarian higher education website is clearly visible so students or prospective students with colour deficiencies cannot obtain the information in the same "easy" way as the ones without impairments. My recommendation for webdesigners is to create websites where it is not only colours that provide information. It means that some patterns or huge contrasts would be efficient for the easy visibility of every text, button or link on their websites.

With this research I wish to draw IT engineers' attention to shortcomings so that they can improve the quality of the service of educational sites, computer games and websites in the future, and grant easy access for users and students with colour deficiencies.

<u>Subthesis II/2.</u> Based on the testing procedures I determined a 12-point requirement list, and I developed an expert questionnaire to test webpages. [4], [17], [37], [38], [54], [57], [58], [60]

I have made interviews with users with special needs in the first phase of the present research. Then, two software validators were imprented to test about 500 websites in 12 countries such as Austria, England, France, Germany, Hungary, Japan, Norway, Peru, Poland, Switzerland, Slovakia, and the United States of America. The applied validators are WebXACT [124] and XValid. [17], [125] With the help of these websites of 15 different categories of the following kinds were analysed: governmental, educational, commercial, online shopping, healthcare, newspapers, TV channels, timetables, banks, free-time, museums, assistive technology-scientific, sports and chat sites. Exhaustive figures were collected based on the data of the testing not only for each country but for countries inside and outside of Europe in the 15 previously listed categories.

Based on the figures, I pointed out the most frequent mistakes. When coming up with my recommendations I took these problems into consideration. After the analysis of the data I focussed on a 50% threshold concerning errors and warnings in all websites involved. I had a closer look at the errors before summarising concrete technical, non-subjective recommendations. Using the following 10-promptly recommendations chart, which is more specific than WCAG 1.0 [108] or WCAG 2.0 [109]), min. 50% of the websites analysed would be barrier-free. Complying with the recommendations is cost-efficient and requires little time.

In the second phase of the research I performed new studies. The primary objective of next study was to examine healthcare-related websites in 9 European countries in order to evaluate the status of their accessibility. Such a detailed statistical comparison had not yet been carried out in Europe, especially as the present study offers a dual measurement system combining both the application of automated testing software and statistical analysis of user feedback. My study compared 48 websites from Eastern Europe with 51 sites from Western and Northern Europe. The research phase was performed in three steps, firstly by using AChecker [121], secondly by Nibbler [126] and subsequently followed by user feedback questionnaires evaluated by a group of experts. The overall goal of this study was to determine the most common accessibility problems and to draw site owners' attention to shortcomings so that they can improve the quality of service of their healthcare-related sites in the future. The concluding findings of the research yielded an additional two recommendations to the ten ones formulated previously.

i. **Provide alternative short texts for all non-text elements (e.g. images), and if one is not able to write a short description, then, use a long text.**
ii. **Use relative and positioning, rather than absolute.**
iii. **The content of the site should be accessible without using a mouse (the appearance of the content should not depend on JavaScript event handlers/modal windows).**
iv. **Use <label> tag defining the elements of the form and where it is not possible to use 'title' attribute.**
v. **The texts of references should to be understandable without their contexts.**
vi. **In the <html> tag identify the primary natural language using 'lang' attribute and specify the base direction of directionally neutral text using 'dir' attribute.**
vii. **Provide summaries for tables using 'summary' attribute in <table> tag.**
viii. **Use separating characters between the links.**
ix. **Check the <title> tag whether it does identify the subject of the webpage correctly.**
x. **The <html> tags should be closed correctly so that the assistive technologies can parse the content accurately and do not have to correct them.**
xi. **All websites must be made responsive so that they can be accessed by any device or platform independently of screen size.**
xii. **Websites should be tested with real users! Involve people with disabilities in the research, design and development process. Include different disabilities with the help of:**
    - **focus groups**
    - **usability tests**
    - **a design and research team.**

<u>Subthesis II/3.</u> I have disproved Goodwin et al.'s thesis [127] that the wealthier a country is (GNI per capita), the fewer barriers will be present on its websites and the larger size of webpages in Kbytes is, the larger barriers will be presented on its websites. So, I have demonstrated that the design of accessible websites is independent of the economic situation and webpages size and also demographic needs. [4]

The investigated European websites in the above mentioned research were grouped into Eastern and Western-Northern countries. The results were compared from different perspectives and ascertained that no significant differences can be established between the two groups predicated on their respective economic situations. Equally, no correlations were observed while comparing the sizes of webpages in Kbytes, the number of barriers. Furthermore, there appears to be no correlation between the results of the software tests and the percentage of the elderly population in the respective country.

Fig. 8 and Fig 9 show that in the case of the AChecker test a larger size does not imply more errors. The estimated value of the correlation coefficient is 0.027, it is very close to 0. The p-value of the test is 0.791, therefore, we accept the hypothesis that these quantities do not correlate. This result is the opposite of what was concluded by Goodwin et al. [127]

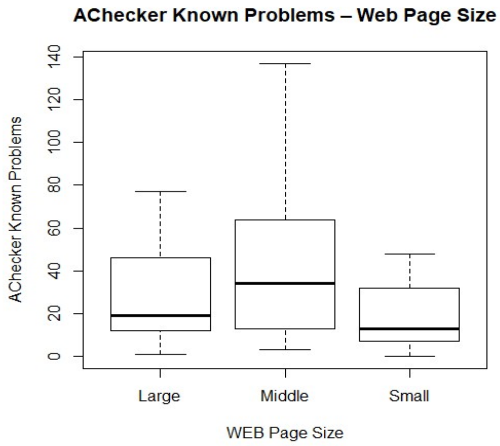


Figure 8: Box-plot of the AChecker-known values in the function of webpage sizes (large, medium, small)

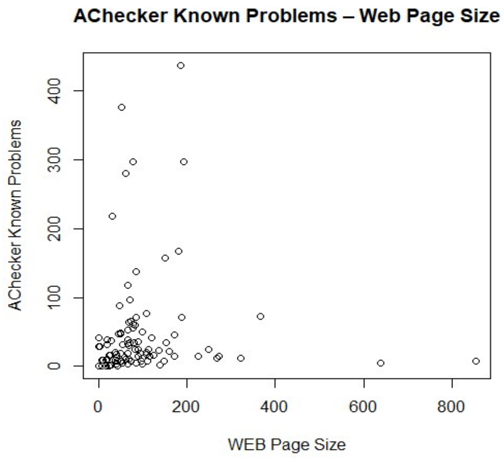


Figure 9: The diagram of the AChecker known values in the function of the web page sizes (Kbytes)

Figure 10 presents the number of AChecker known errors in the function of the GNI Per Capita.The correlation coefficient is estimated to be -0.097, thus the hypothesis of independency can be accepted on a significance level of 0.169.

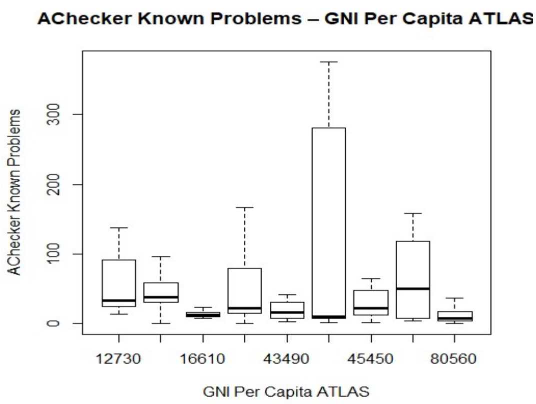


Figure 10: The box-plot of the AChecker-Known Problems in the function of the GNI Per Capita

<u>Third group of theses: Universal Design and Health IT:</u> I conducted a research on barrier-free design of both multimedia and VR games. For these I also suggested recommendations, design methods and testing methods. Based on the recommendations of the previous group of theses, I proved that it is possible to create a barrier-free website.

<u>Subthesis III/1.</u> I created the design requirements and testing methods of customisability concerning serious multimedia and VR games for skills development and rehabilitational use. [2], [15], [18-24], [39], [44-53]

Thanks to the GOET [128] project and 20 years of game developing, we were able to create many multimedia and VR games to help the intellectually disabled youngsters carry on with their everyday lives. First, I had to carry out a survey to obtain information on the users' demands from both pedagogical and user interface design points of view. Based on a great number of tests, I created my own testing criteria. As part of the GOET project, we did both domestic and foreign testing (in our partner countries, i.e. Belgium, England and Lithuania). The children with inltellectual disability had to play the software twice a week for 6 weeks for at least 20 minutes/day. For the usability test, I put together a questionnaire that was made up of 40 questions. Special-needs schools that had taken part in our pedagogical examinations were asked to fill out these questionnaires, moreover, teachers and parents of children with disability were also involved in the survey. The research results obtained in the GOET project [128] were also useful in the ISG4Competence project [129].

We have been developing rehabilitation software for stroke patients since 2004 as parts of several projects. One of them is a project called StrokeBack [116] gave us the grounds to create many VR- and multimedia-based games, and motivational-educational animations. During the research and development work not only did I contact therapists but patients with special needs and skills were also taken into consideration. Based on the serious game development for the telemidical system, I realized that traditional software development models are not applicable. Therefore, I created a new software development method based on the needs of patients and therapists and I created the following Specification of Requirements:

- **Functional requirements:**
  - the evaluating framework should not be negative, is should be made motivational for the patient instead,
  - instructive animations may demonstrate all kinds of movement to be practiced prior to each game,
  - clear and straightforward feedback on the task and movement is needed,
  - let the user choose from different stories in the games,
  - a relevant motivational animation should be featured after each game,
  - make the game customisable with the help of a level editor.

- **Non-functional requirements:**
  - all games must run in an extendable framework,
  - the games should match each other in their structures and style
  - the previously written elements may be used in the framework to avoid redundance.

<u>Subthesis III/2.</u> I proved that accessible health-related websites can be created based on my accessibility recommendations (Subthesis II/2). In addition, the use of such websites improves nursing workflow, efficiency and patient education. [29]

The use of websites to provide patient education is becoming more common. The benefits of a properly executed and effective preoperative patient educational intervention have been shown to result in improved psychological and physical well-being for patients undergoing surgery. The purpose of this pilot study was to determine the usability, utility, and feasibility of a website we created to increase engagement and improve the quality of the preoperative education patients receive in preparation for hip and knee arthroplasty. Eighty patients who met the inclusion criteria were recruited, aged between 40 to 65, among those 52.5% were female, 71.25% were placed for knee replacement, 28.75% for hip replacement. Forty patients were randomly assigned to paper education cohort, 40 to the paper and website education cohort. However, only 19 from each cohort participated in the survey questionnaire. The outcome of interest included qualitative data for patient knowledge, satisfaction, utilities, and usability, which were assessed based on the Perceived Health Website Usability Questionnaire online survey. The paper-based survey contains ten questions using a 7-point Likert scale while the web-based survey contains fourteen questions using the same 7-point Likert scale. Descriptive statistics and independent samples t-tests were used for comparative analysis of usual paper education and website education cohorts; whereby Microsoft Excel data analytics tool was used to compute the results. The Alpha level was set to 0.05 for the statistical results. The result of the study showed no statistically significant differences in both cohorts at the 0.05 level. According to the survey result for the nursing staff, the use of the website improved nursing workflow, efficiency, and patient education.

Figure 11 illustrates the accessibility testing of the website by AChecker [121] used in the research.

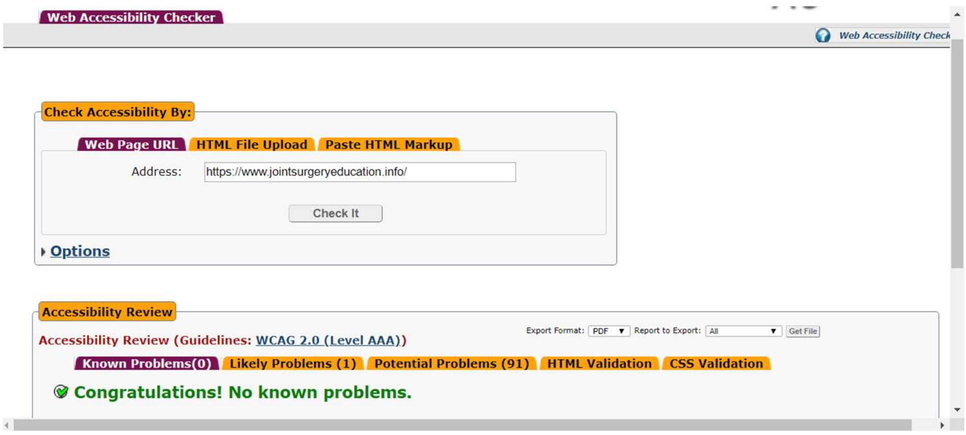


Figure 11: Screenshot of the AChecker automated tool (after the test, showing the results).

IV. Applying new scientific findings

My research was aimed at studying problems which either have not been solved, or have been discovered recently, and I also put forward recommendations to work these problems out.

As a software engineer, I have always wondered how much the software I develop is usable for others, including not only the functions but also the design of the user interface. Meanwhile, under the guidance of Professor János Schanda, I learnt a lot about colours and became interested in colour science research. But I also realized that there was very little software developed for special needs user groups in the beginning. Thus, my interest expanded in the field of barrier-free design.

My scientific contributions mainly concerned the international projects financed by the European Union, listed below, of which I was the Hungarian project leader.

The "Colour Research for European Advanced Technology Employment" CREATE (MSCF-CT-2006-045963) project [130] primarily served the training and further training of future professionals and researchers in the field of colour theory, on undergraduate and Ph.D. levels alike. In this project I gave lectures several times at semi-annual trainings in different European countries. After the closure of the project several books were published, now these are used in the teaching of colour science at various universities in Europe. My contribution, specifically described in Thesis I/1, I/2, and II/1, was given an important role in the books to which the editors invited me. [56-59]

I worked actively in several groups in the “Design for All for eInclusion” DfA @ eInclusion 033838 project. [131] Thesis II/1 and the first research of Thesis II/2 contain in detail the scientific results that were utilized in this project, mainly in the “Standaradisation” and “Technological Development” work packages. I was not only the Hungarian leader of this project but also the coordinator of the international project with the participation of 23 countries for one year. As a result, the book I edited, entitled “Principles and Practice in Europe for e-Accessibility”, was born as a dissemination activity of the project. [70]

Parallelly with the DfA project I worked as a Hungarian project leader in the web_access project “Joint Program on Accessible Web Design” (133818-LLP-1-2007-1-AT-ERASMUS-ECDEM). [132] As part of the project, we developed a 120-credit blended-learning course with 5 Western European universities to facilitate barrier-free web design and assistive technology education. The results described in detail in my first research of Thesis II/2 were also used in this project. After closing the international project, I developed the 60 ECTS “Barrier-Free Web Designer” and also the 60 ECTS “Assistive Technology” engineering courses for the University of Pannonia, which were successfully accredited.

I cannot emphasise enough the importance of the findings that are used in practice. The findings of the researches enabled considerable progress in the work I did with my students (via projects GOET, StrokeBack, ISG4Competence) [128], [116], [129]; these developments are currently used by our partners in 9 different Europen countries. All these developments are described in detail in the dissertation and the III/1. subthesis based on them.

Also, as a result of the publications based on Thesis III/1, I was invited to the LUDI - TD COST Action TD1309 - “Play for Children with Disabilities” international consortium. [133] I was also a member of the Management Committee in the international project that ended last year. During the project my results in Thesis I/1, I/2, and III/1 were directly used. I closed this international project with a book chapter co-written with my former Ph.D. student. The title is „Play for children with disabilities: some reflections on the results on the users’ needs and on the role of technologies”. [67]

Thesis III/2 further supports my research results in Theses II/1 and II/2. The statement in Thesis III/2 is also supported by a statistical analysis of a questionnaire completed by the medical staff and patients of a public hospital in Baltimore (USA). [29]

In the international project starting at the time of submitting this dissertation I am not only a domestic project leader but also a member of the Management Committee: (COST CA19104) “Advancing Social Inclusion through Technology and Empowerment”. [134] The subject area of this also overlaps significantly with my research in both colour and barrier free design.

I have received many references and quotations of my new scientific findings both in the fields of barrier-free and colour design. The theses may be well-used to design and test multimedia and VR games as well as creating barrier-free websites and accessibility and usability testing.

Moreover, my findings can also be used in education. Seeing my achievements, I have been featured lecturer in several international conferences. It is very important that my work is internationally acknowledged and that is why I got the chance to organise the Association for the Advancement of Assistive Technology in Europe (AAATE) [135] conference in Hungary in 2015. In addition, I receive numerous invitations for reviewing international projects and journal articles.

V. University lecturer and publication work

In addition to my research and teaching activities, which are mainly related to the University of Pannonia, I was an invited lecturer at the Faculty of Information Technology and Bionics of the Pázmány Péter Catholic University (PPKE), where I held lectures in the subject of "Design user interface". I am also a regular guest lecturer in the vocational training of rehabilitation engineers at the Budapest University of Technology and Economics and the University of Óbuda.

I defended my habilitation application at the University of Pannonia in 2017.

During my teaching activities I have been the supervisor of 3 Ph.D., 111 M.Sc., 93 B.Sc., 53 TDK dissertations, and 14 Innovation Competition Work. My undergraduate and doctoral students have won numerous awards.

From 1998 I was the secretary of the Applied Light and Colour Work Committee of the Veszprém Regional Committee of the Hungarian Academy of Sciences for 10 years. I was also a regular speaker at workshops and conferences organized by the committee.

In 2009 I founded the Human-Computer Interaction & Design for All Section of the John von Neumann Computer Science Society (NJSZT), of which I was the chairman for 10 years, subsequently I handed over the presidency to my former doctoral student, and since then I have been the vice-president of this section. I am a professional advisor to the Multimedia in Education Section of the NJSZT. I am also an active member of the Medical Biology Section of the NJSZT. I am a regular annual speaker at the conference organized by all three sections. My publications are closely related to my Theses presented.

Appendix B

Virtuális világok színhelyes és akadálymentes tervezésének tesztelési módszerei

MTA doktori értekezés tézisei

Sikné dr. Lányi Cecília, Ph.D.

Pannon Egyetem

Villamosmérnöki és Információs Rendszerek Tanszék

Virtuális Környezetek és Alkalmazott Multimédia Kutatólaboratórium

Veszprém, 2020

I Az értekezés tárgya, előzmények, célkitűzés, motiváció

A számítástechnika, informatika és a rendelkezésre álló számítási kapacitás fejlődése révén egyre valósághűbb képi megjelenítés válik lehetővé. Ezen fejlődés eredményeként új tudományágak jöttek létre, pl. a számítógépes grafika, virtuális valóság. Ennek a folyamatnak egy érdekes és kihívásokkal teli része a színhelyes megjelenítés kérdése. A kapcsolódó kutatások egyik létfontosságú területe a felhasználói igényekre, ezen belül az akadálymentesítés területére összpontosít. A jelen értekezés egyik fő törekvése például az olyan webes akadálymentesítési ajánlások legitimizálásának elősegítése, melyek a színtévesztő vagy egyéb látási nehézséggel küszködő emberek számára lehetővé teszik az interneten található információk akadálymentes elérését.

Az internet megjelenésével az információátadás felgyorsult, megjelentek a közösségi hálózatok, online játék-közösségek. Ez a dimenzió több millió felhasználót ölel fel. Mind a közösségi hálózatok, mind az online játékok felfoghatók egy-egy virtuális világnak.

Az elmúlt két évtizedben a kutatómunkám két területhez kapcsolódott: egyrészt a számítógépes szoftverek színhelyes megjelenítésének témaköréhez, másrészt az alkalmazások akadálymentes tervezéséhez. A két terület szorosan kapcsolódik egymáshoz, mivel a felhasználók minimum 10%-a valamilyen fogyatékossággal rendelkezik. [71] A jelen értekezés következésképpen ezen két területet öleli fel:

- szoftverek, beleértve a virtuális játékok és weblapok színhelyes tervezése,
- szoftver ergonómia, különösen az akadálymentes tervezés, hogy bárki könnyen tudja használni az adott szoftvert, weblapot. Lehet az akár játék, oktatási anyag vagy egészségügyi, orvos informatikai rehabilitációs alkalmazás.

A virtuális környezet (Virtual Environment VE): egy szintetikus, térbeli (általában 3D) világ a felhasználó nézőpontjából, mely valós időben kontrollálható. Néhány irodalomban a virtuális valóság (Virtual Reality VR) és virtuális környezet (VE) többé-kevésbé egyet jelent [72]: a virtuális környezeteket az alapján különböztetik meg a többi szimulációs rendszerektől, hogy azok képesek-e háromdimenziós (3D) térbeli információk különböző módokon való ábrázolására, képesek-e a felhasználók természetes interakcióit használni, amennyiben „belemerítő” rendszerről van szó. [68] A belemerítő rendszerek hatása a felhasználóra egy szintén élvonalbeli kutatási terület. [69] Itt is új kutatási terület lehet a kis és nagyméretű felületek színhatása, amire a valós világban sok kísérlet és kutatás létezik. [73,74]

Egyre több internetes, háromdimenziós (3D) játék található manapság. Steinkuehler vizsgálta az elmúlt években a legnépszerűbb három globális közösségi VR játékot. Ezeknek összesen több mint 9,5 millió felhasználója van szerte a világon – ez a „lélekszám” felveszi a versenyt, például a legtöbb amerikai metropolisz lakosságszámával.[75] Azonban egyre nagyobb az űr a virtuális hősök és a való világbeli emberek tulajdonságai között. Ez a különbség látható a színek megválasztásában is. Érdekes hipotézisként bebizonyosodott, hogy a VR játékok színezése befolyásolja-e a felhasználók memóriaszíneit. Ezért kutatási célként tűztem ki a különböző VR játékok színezésének vizsgálatát, összehasonlítva az irodalomban található memóriaszínekkel. [76,77]

A kulturális különbség tanulmányozása egy feltörekvő kutatási terület lett az elmúlt évtizedben. A kulturális különbségek hatással vannak a felhasználók információval való interakcióikra. [78-80] Az elmúlt másfél évtizedben a kulturális különbségek tanulmányozását a színtan területén végeztem.

Köztudott, hogy a színek hatással lehetnek az emberi érzelmekre, érzésekre, abban az értelemben, hogy egyes színek boldogságot, míg néhány szín deperessziót is kiválthatnak.[81] A kultúrák közötti vizsgálatok azt mutatják, hogy a különböző kulturális csoportok eltérő válaszokat és preferenciákat mutatnak a színek [82] és a színkombinációk vonatkozásában. [81,83]

Sato és munkatársai [84] három tulajdonság alapján végeztek vizsgálatokat: a színek befolyásoló hatása, a színezetdússág és hideg-meleg színek vizonyát vizsgálva. Smet és munkatársai [85] különböző kontinenseken végeztek szín memória vizsgálatot. Ebből a pár kutatásból is látszik, hogy a színekkel való kísérletek gyakran pszichofizikai kísérletek.

Multimédiás alkalmazások sokszor használnak grafikus rajzokat a fényképek helyett, mert ezek hatékonyabban tárolhatók és mozgathatók. Sok esetben a felhasználók megfelelőnek tartják a kevés színnel színezett képeket is. A virtuális valóság (VR) szimulációkban (elsősorban terápiás célokra) a minél élethűbb megjelenítés az elvárt. A grafikus kép készítőjének, a 3D modellezőnek választania kell a tulajdonságokat reprezentáló színek sokaságából. A legtöbb modellező szoftver a színek széles skáláját engedi használni a saját palettájáról, de nem sok útmutatást ad arra vonatkozóan, hogy hol és melyiket érdemes alkalmazni. Régebben a képek színezése a grafikus feladata volt. Manapság ez is az animációt programozó informatikus mérnökre, animátorra hárul. A képnek van esztétikai értéke is, ami annyit jelent, hogy a választott színek nem lehetnek kaotikusak, harmonikus egységet kell alkotniuk. Színharmóniákra számos irányelv létezik.[86] Virtuális múzeumok kapcsán pedig elvárt lenne, hogy a múzeumi tárgyak, festmények valósághűen kerüljenek bemutatásra.

A tudományos előzmények között meg kell említeni a színtan oktatásához készült multimédiás oktatóanyagunkat is.[1] A színtani kutatások egyik kiemelt területe, hogy a valamilyen színtévesztéssel rendelkező felhasználók hogyan látják a szoftverek felhasználói felületét, weblapokat. Az emberiség számának növekedésével a színtévesztők száma is nő. Ez nem elhanyagolható, hiszen több százmillió embert jelent. [87,88] A szoftverek tervezésénél tehát nemcsak arra kell ügyelnünk, hogy a felhasznált színek harmonikusak legyenek, hanem a különböző színek használata során ne fordulhasson elő az, hogy egy színtévesztéssel élő felhasználó számára valami nem látható. Azaz számára is akadálymentesen lehessen használni az adott szoftvert, illetve weblapot.

Az utóbbi időben határozottan fellendült az akadálymentes tervezés területén a kutatás, növekvő számú cikk, számos fontos alkalmazás látott napvilágot. A korlátozott terjedelem miatt ezek itt nem kerülnek felsorolásra [89,90] (a saját válogatott publikációkon kívül) [2,3,30-33,55], inkább statisztikai adatokkal támasztom alá az akadálymentes tervezés fontosságát és időszerűségét.

Az Európai Bizottság prioritásai között szerepel a modern digitális szerződéses szabályok egyszerűsítése és a digitális tartalomhoz való hozzáférés támogatása, valamint az online értékesítés növelése. [91,92] Támogatni kívánják a digitális piaci stratégiát a tagországokban. Továbbá új e-kereskedelmi szabályokat vezetnek be, hogy könnyebb legyen vásároni és eladni temékeket az EU-ban.[93] Magyarországi adat, hogy 2015-ben több mint 22 milliószor vásároltak terméket online.[94] A magyarországi online kiskereskedelem forgalma 18 százalékkal bővült 2016 első fél évében az előző évhez képest, és elérte a 131 milliárd forintot.[95] Ez a szám egyre csak növekszik. A mintegy 3200 magyar webáruházzal rendelkező e-kereskedő bevonásával készült felmérés alapján a hazai online kiskereskedelem 2018-ban elérte a nettó 425 milliárd forintos éves forgalmat, ami mintegy 17%-kal múlta felül a 2017-es szintet és 4,5%-át adja a teljes magyar kiskereskedelmi forgalomnak.[96] A hetedik éve készülő, szektorszintű felmérés alapján a hazai online kiskereskedelem 2019-ben elérte a bruttó 625 milliárd forintos éves forgalmat, ami mintegy 16%-kal múlta felül a 2018-as szintet. Az online értékesítés adja a teljes magyar kiskereskedelmi forgalom 6,3%-át.[97]

Ráadásul az online vásárlók több mint fele már vásárolt egy külföldi webáruházból. [98] A magyar fogyasztók 2019-ben bruttó 145 milliárd forintért vásároltak a külföldi webáruházakban. [99] Több mint 50 000 új kezdő online vásárló jelent meg az online piacon a járvány kezdetén másfél hónap alatt. [100] A WHO 2020 március 11-én világjárványnak minősítette a COVID-19 koronavírus-fertőzést. [101]

De ne csak az online kereskedelemre gondoljunk, hanem sokkal szélesebb területű internet használatra. Ha a közelmúlt eseményeit nézzük, a Covid-19 járvány kitörése az otthoni munkavégzést normává tette többmillió munkavállaló számára az EU-ban és világszerte. Az Európai Bizottság Közös Kutatóközpontjának új elemzése feltárja azokat a kihívásokat, amelyekkel az országok, a munkaadók és a munkavállalók szembesülnek az új otthoni munka környezetben. [102,103] Sok-sok millió ember kényszerült othonról dolgozni és otthonról tanulni, a háziorvosi távellátásról nem is beszélve. Ez a szükségesség és a home office igénye is alátámasztja mennyire fontos az internet akadálymentesítése.

A legtöbb szoftvergyártó cég eddig nem gondolt kiemelten a speciális igényű felhasználókra, mert nem látták a potenciális piacot ezen felhasználók körében. Azonban statisztikai adatok bizonyítják, hogy a világ népességének minimum 10%-a él valamilyen formában fogyatékossággal. [71] Az USA-ban ez a szám a becslések szerint 14% és a 65 év feletti népesség 65%-a tekinthető fogyatékossággal élőnek. A fogyatékosság szorosan összefügg az életkorral. A fejlett társadalmakban egyre több ember lesz 75 évesnél idősebb, akik nagyobb valószínűséggel rendelkeznek valamilyen károsodással. Ez a csoport 14,4% -át fogja kitenni a lakosságnak 2040-re, szemben a 2003-beli 7,5%-al, azaz mintegy a kétszeresére növekszik.[104]

Továbbá, 2020-ra az Európai-Unió (EU) lakosságának 25%-a 65 év feletti lesz. A nyugdíjakra fordított összegek, az egészségügy és a hosszú távú gondozás várhatóan növekedni fog és 4-8% a lesz a GDP-nek az elkövetkező évtizedekben. Az ilyen jellegű kiadások megháromszorozódnak 2050-re. De arra is gondolni kell, hogy az idősebb európai lakosság „vagyona” több mint 3000 millárd €. [105] Az a cég, amelyik nem számol azzal, hogy akadálymentesen nyújtsa termékeit és szolgáltatásait, a fogyasztóinak/felhasználóinak jelentős részét el fogja veszíteni.

Új megoldásokra van szükség az idősek mindennapi gondozásához és egészségügyi monitorozásához, akik esetleg nem tudnak elköltözni otthonukból [106], pl. digitális e-health egészségügyi szolgáltatásokra és a távolból való digitális szociális gondozásra van szükség. [107]

Ehhez elengedhetetlen a szoftverek, az intenet akadálymentessé tétele. Az internet, a szoftverek, VR alkalmazások akadálymentesítése nem egyszerű feladat hiába létezik az egyetemes, „mindenkinek tervezés” elve és szempontrendszere [70,89,90], hiába léteznek különböző szabványok és előírások az internet akadálymentesítésére. [108,109] A kérdés bonyolultabb, ha a felhasználó speciális igényeit is figyelembe kell venni. Ezért is végeztem kutatást, hogy összeállítsak egy minimális követelménylistát, amit minden szoftvermérnöknek, informatikusnak és webes tervezőnek figyelembe kellene vennie. [2,3,30-33,55]

A kiterjesztett valóság (Augmented Reality AR) és a virtuális valóság (VR) globális piacának becslései szerint 2020-ban 22,1 milliárd USD bevételt generálnak, és a növekedés 2025-re várhatóan eléri a 161,1 milliárd USD-t, ami az előrejelzési időszakban 48,8% összetett éves növekedési rátát jelent. A piacot olyan tényezők mozgatják, mint a növekvő reagálás ezen technológiák iránt, az AR és a VR technológia gyors elfogadása a különböző iparágakban, valamint az AR és a VR összeolvadása a vegyes valóság kialakítása érdekében, amely megvalósítható a leendő alkalmazásokhoz.[110] A VR/AR iparág gazdasági elemzői az elkövetkezendő 10 évben 182 milliárd dolláros növekedést prognosztizálnak. Ebből 110 milliárd a hardver és 72 milliárd a szoftver.[111] Mivel az olyan vezető szoftvercégek, mint a Microsoft egyre inkább törekszenek az akadálymentes szoftverek kiadására, a játékiparban is egyre több igény merül fel az akadálymentes tervezésre.

Összefoglalva, a népességi adatokból, a felhasználók igényeiből és az e-kereskedelmi, e-health törekvésekből látszik, mekkora igény van az akadálymentes szoftverekre és internetes elérhetőségre. Mindehhez hozzájárul a színhelyes tervezés fontossága is. [5-8]

Az értekezés legfőbb célja, hogy a felvázolt felhasználói akadályokra és problémákra mérések és statisztikai elemzések alapján megoldásokat javasoljon az életminőség javítása érdekében; valamint tesztelési módszereket, ajánlásokat készítsen felhasználóbarát, színhelyes és akadálymentes internet és szoftverek tervezéséhez.

II Alkalmazott eszközök és vizsgálati módszerek

A tézisfüzetben összefoglalt eredményeket a szűkebb szakterület hagyományosan elfogadott módszereivel értem el. Kutatómunkám során, ahol csak lehetséges volt, törekedtem az objektív vizsgálatokra, mérésekre. Látás-pszichofizikai vizsgálatokra különféle pszichofizikai módszereket lehet alkalmazni. A színtani vizsgálatokhoz a kísérletek, mérések egyrészt objektív mérési módszeren alapultak:

- szoftveresen – a Photoshop Eydrop tool segítségével,
- mérőműszer segítségével - az X-rite Eye-One (i1), Minolta, Spectrascan spektro-colorimetert-használva,
- a témavezetett hallgatói kutatócsoportom által készített teszt-szoftverek segítségével,
- Microsoft Excel adatelemző szoftver használatával,
- R (R 3.5.0 verzió) statisztikai program csomag használatával,

másrészt a színmemóriára vonatkozó kísérletek szubjektív pszichofizikai vizsgálattal készültek.

A Human-Computer Interaction: a szoftver-ergonómia területéhez tartozó akadálymentes tervezési kérdésekben a méréseket egyrészt objektív módszerrel, a témavezett hallgatói kutatócsoportom által készített tesztszoftverekkel, nemzetközileg elfogadott validáló szotfverrekkel; másrészt humán kérdőívekkel végeztem: a hallgatói kutatócsoportom által készített játékok felhasználói felületre, illetve használhatóságára vonatkozó vizsgálatokkal.

A kérdőívekből nyert adatok leíró statisztikai jellemzők kiszámításán túl matematikai eljárások alkalmazásával kerültek vizsgálatra. A webhelyek átlagos hibaszámának azonossága különböző csoportosítások révén is összehasonlításra került. Az egyes hibatípusok gyakorisága, egyes feltételek teljesülése esetén a hibatípusok arányának egyezősége is a vizsgálatok tárgyát képezte. Pearson korrelációs együttható alkalmazásával vizsgáltuk a hibajellemzők országjellemzőkkel való összefüggőségét (pl idős populáció aránya), valamint az egyes tesztelő programok által talált hibaszámok korrelációját. A nullhipotézis a korrelációs együttható 0 értéke volt, mivel normális eloszlás esetén ez egyben függetlenséget is jelent. A vizsgálatok szerint nincs korreláció a vizsgált teszttípusok eredményei között, ami azt mutatja, hogy az egyes hibadetektálók más-más jellegű hibákat jeleznek. Az országok közötti hasonlóságok a k-means klaszterezési eljárással is kimutatásra kerültek. Az összes statisztikai számítást az R statisztikai programcsomag segítségével történt (R verzió: 3.5.0.).

A nemzetközi együttműködéssel foytatott kutatási-fejlesztési projektek keretében, laboratóriumi kísérletek és oktatási, rehabilitációs megfigyelések révén kidolgozott eljárásokat, kérdőíveket részletesen a téziseknél feltüntett publikácókban ismertetem. Tevékenységem egyik fontos elemét éppen az képezte, hogy a szoftvergonómiai elvek milyen módon és mértékben vezethetők át a szoftvertervezés napi gyakorlatába.

A tézisfüzetbe azon eredmények kerültek a PhD fokozat, illetve a habilitáció megszerzése óta, amelyekben a hozzájárulásom lényeges volt, amelyekben a saját munkám túlnyomónak mondható. Pár publikációtól eltekintve, melyek Schanda János professzor úrral közösen végzett kutatás eredményei, a publikációk döntő többsége a saját témavezetett B.Sc., illetve M.Sc. és egy esetben PhD hallgatóval végzett közös munkából születtek, ezekben az esetekben társ-szerzőkként tüntettem fel őket. A megállapítások, tézisek a társ-szerzőim hozzájárulásával kerültek ide.

Az egyes tézisek ezeket a publikációkat többnyire időrendben tartalmazzák. Az elmúlt másfél évtized csupán 70 saját publikációját (terjedelemi korlát miatt) soroltam fel a tézisekhez és előzményeihez, de ennek a számnak többszöröse is igazolja a tézisek állításait. (Az MTMT oldalán az itt fel nem sorolt publikációknak elérhetősége megtalálható.)

III Az új tudományos eredmények összefoglalása tézisekben

A tézisek az alkalmazott kutatási eredményeimnek tömör összefoglalását tartamazza. Téziseimet témáik szerint három téziscsoportba solom.

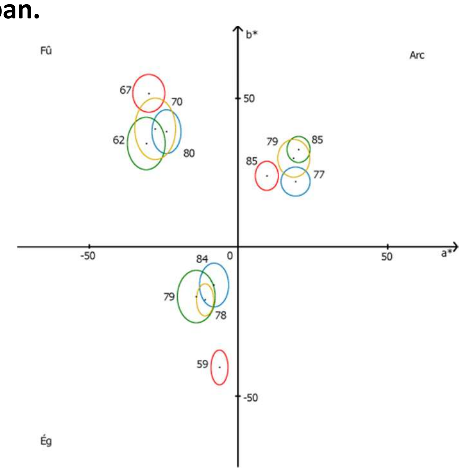
I. <u>TÉZISCSOPORT: Színtervezés területén:</u> A virtuális világok nem valósághű színekkel jelenítődnek meg, abban az esetben sem, amikor a színhelyes megjelenítés elvárt lenne, ami befolyásolja a memóriaszíneinket.

<u>I/1. altézis</u>: Mérések alapján megállapítottam, hogy nem valósághű színeket használnak a képregénykészítők és VR játékfejlesztők. [9], [34], [56-59]

A mérésekhez több mint 300 grafikus képet, elsősorban képregényt, gyűjtöttem minden földrészről. A képek csoportosítása alapján meghatároztam, hogy melyek azok a tulajdonságok, melyeket érdemes kiemelten vizsgálni. Szinte minden képnek van szereplője, akiknek van arcuk, hajuk (szőke, barna, fekete, vörös). Sok a tájkép (európai és japán esetben), tehát vizsgálhatjuk az ég, a felhő, a tó, a fű, a lomb, a fatörzs és a homok színeit.

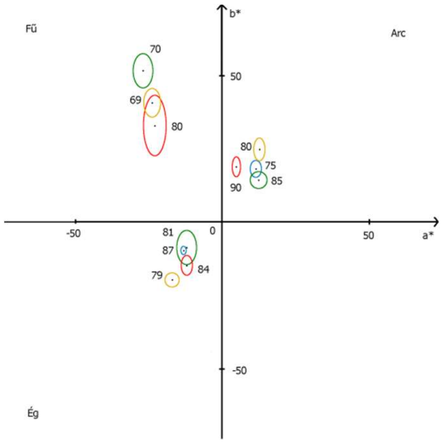
A kategóriák és a vizsgálandó tulajdonságok megállapítása után egy relációs adatbázis készült az adatok tárolásához. Az adatbázisban tároltam minden fontos adatot, amire később szükség lehet a kiértékelésnél. Helyszín szerint is csoportosítottam a képeket: tájkép, belső tér, város, portré, stb. Méréseimhez a CIELAB színrendszert használtam. [112] Az RGB és CMYK rendszerekkel ellentétben ez egy berendezés-független színábrázolási mód, amely a színábrázolás egyik nemzetközi szabványa. [113] A CIELAB színtér elméletben minden szín ábrázolására alkalmas, ezért is lett ez a színinformáció átvitelének az alapja. A CIELAB modellben meg kell adni a világosság (L) mellett a színesség helyét az a*, illetve a b* skálán, amelyek a zöld és vörös, illetve a kék és sárga közti egyensúlyt határozzák meg. A színeket három jellemző szerint kategorizálhatjuk: világosság, telítettség, színezet. Papíron szerzett képregények (hard-copy) színeinek mérése egy kézi spectro-colorimeterrel történt. A mérés beállítása: CIE Illuminant D65-ös megvilágítás és 2 fokos észlelő. Az Internetről vett képek (soft-copy) mérése az Adobe Photshopban történt, a Sample Tool segítségével mintákat vettem a különböző tulajdonságokból és ezek az adatok kerültek mentésre az adatbázisban. A mérések alapján a következőket állapítottam meg:

I/1.1. Japán internetes képregények színezésekor a telítettebb, erőteljesebb, sokszor a sötétebb színeket használják, míg az európaiaknál a halványabb, világosabb színeket részesítik előnyben. Arcszín választásánál a japán szín sokkal halványabb, de semmiképpen nem nevezhetjük sárgásnak, ahogy a valóságban.



1. ábra: Három jellemző tulajdonság eredményeinek ábrázolása az a, b* grafikonban. Kék az amerikai, zöld az ausztrál, piros a japán és sárga az európai soft-copy értékek. A középpont az átlagérték, az ellipszis sugara az a*, b* szórás értékei, L* értéke az ellipszisek mellett szerepel.*

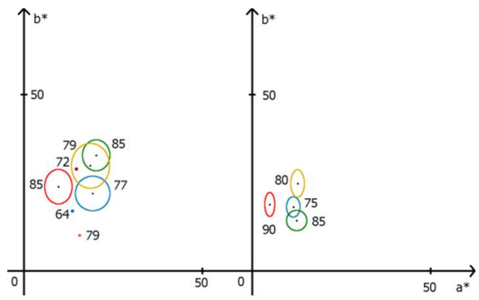
I/1.2. Nyomtatott képregény-papírképek esetében a japán színek a leghalványabbak, és az ausztrálok a legélénkebbek.



2. ábra: Három jellemző képrészlet eredményeinek ábrázolása az a, b* grafikonban. Kék az amerikai, zöld az ausztrál, piros a japán és sárga az európai hard-copy értékeket jelöli. A középpont az átlagérték, az ellipszis sugara az a*, b* szórás értékei, L* értékei az ellipszisek mellett szerepelnek.*

I/1.3. Az amerikai képregényekben bizonyos tulajdonságok (kékes-zöld arcszín, a sárgás táj) színei egészen távol állnak a valós színektől.

I/1.4. Hard-copy (nyomtatott) színek összevetése a soft-copyval (monitor) nemzetenként: a papíron mért eredmények kicsit fakóbbak, nem olyan élénkek, mint az Internetes (soft-copy) képek, ezek általában sötétebbek is. Legtöbb esetben a japánok színezési szokásai térnek el a többi kultúrterülettől. A japánok használják a legélénkebb színeket a monitoron megjelenített képeknél, de a papírkép eredményeik viszont világosabbak.



3. ábra: Az arcszín eredményeinek ábrázolása az a, b* grafikonban. Baloldalt a soft-copy, jobboldalt a hard-copy eredmények láthatók. Kék az amerikai, zöld az ausztrál, piros a japán és sárga az európai ellipszisek. A középpont az átlagérték, a sugár az a*, b* szórás értékei, L* értéke az ellipszisek mellett szerepel. Narancs pont: Bartleson [114], bordó pont: Tarczali [115], kék pont: a műszerrel mért átlageredmény.*

A virtuális játékok színeinek kutatátásában (stílust, tartalmat és a grafikát figyelembe véve) osztályoztam a legdivatosabb virtuális játékokat. Nyolc csoportot alakítottam ki: 1. Action, Adventure, Mystery Games, 2. Children's Games, 3. Driving & Racing, 4. First-person Shooters, 5. Simulations, 6. Role-playing Games, 7. Strategy, 8. Sports. Mindegyik játékcsoporton belül 7-10 játékból kerestem összesen 752 képet az Interneten, majd 20 játékból, amiknek volt film párja, 179 képet választottam ki. A képanyagot eltároltam a forrás megjelölésével egy-egy könyvtárba. A képeken látható objektumoknak (fa, fű, lomb, ég stb.) és lényeknek (az adott játék szereplőinek bőrszíne, hajszíne) Adobe Photoshop-pal meghatároztam a színi tulajdonságait és ezeket a forrás megjelölésével eltároltam egy adatbázisba. Több mint 4500 mérési adatot kaptam. Ezen adatokat statisztikailag elemeztem (átlag, szórás) és hasonlítottam a képregényekben használt átlagos színekhez, és a memóriánkban tárolt színmemória színekhez. A méréseket a CIELAB színrendszerben végeztem. Vizuálisan két-két szín közötti különbséget jelzőkkel (nagy kicsi stb.) minősítjük. Ennek a CIELAB színrendszerben a világosságkülönbségből és az a^* b^* koordinátákból a következőképpen meghatározott mennyiségek felelnek meg: Δh_{ab} színezeti szög különbség (h_{ab} = arctan (b^*/a^*)) és a ΔC^*_{ab}színezet-dússág különbség ($C^*_{ab} = (a^{*2} + b^{*2})^{1/2}$). Ezek mérésével, illetve számításával állapítottam meg a következő tézisekhez tartozó állításokat.

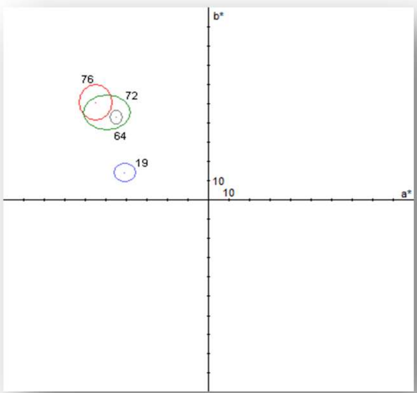
I/1.5. VR játékok arcszínezete sárgásabb a memóriaszíneknél, az Action, Adventure, Mystery Games; Driving & Racing Games; First-Person Shooters Games játékoknál barnás arcszíneket használnak kaukázusi bőrszín esetén is. A valósághoz közelebb álló arcszíneket használnak a gyermek, szimulációs és stratégiai játékokban.

I/1.6. VR játékok zöld fű színezete (gyermek és szerepjátékok kivételével) sötétebb és barnásabb, mint a memóriaszíneink. Ebben az esetben is a VR játékkészítők nem valós színeket használnak a fű színezésére. Filmek esetén az Action, Adventure, Mystery Games fű színe sokkal sötétebb és barnásabb, mint a memóriaszíneink.

I/1.7. VR játékok égbolt-színe az Action, Adventure, Mystery Games; First-person Shooters Games játékokban nagyon szürke. Filmek általában világosabb színű eget használnak, mint a hozzá tartozó játék kategóriabeli színek. Az Action, Adventure, Mystery Games csaknem fehér színű eget, míg a First-person Shooters Games lila színárnyalatot használnak.

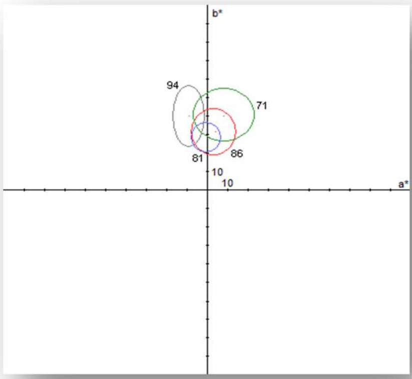
I/2. altézis: A VR világok hamis színe befolyásolja a memóriaszíneinket. Az értelmileg akadályozott diákok, nem játékfüggő diákok és VR játékfüggők memóriaszíne eltérő. [9], [35]

A memóriaszíneket, mint kifejezést azon jól ismert tárgyak színeinek leírására használjuk, melyekre valamilyen régi, vizuális élmény alapján visszaemlékezünk. A memóriaszínek nem a tiszta színemléket jelentik, amit színmemóriának hívunk, hanem úgy tekintik azokat, mint a mindennapi életből jól ismert tárgyak egyéni színemlékeit. Ezek a színek a gyakori ismétlődő észlelésük miatt aránylag stabilizálódnak. Ezek olyan színek, amiket nagyszámú színes minta alapján választunk, ha megkérjük az illetőt, hogy mutassa meg milyen az emberi arcszín vagy az ég kékje stb. Minden embernek van gyakori vizuális élménye a mindennap látott emberekkel (bőrszín), tárgyakkal, vagy tájelemekkel (tájkép: ég, lomb, víz) kapcsolatban, melyek az ember emlékezetében az ún. memóriaszíneket eredményezik. A kutatásbeli vizsgálathoz a megfigyelőknek egy, a hallgatóim által készített szoftver segítségével fekete-fehér képeket kellett kiszínezni.



4. ábra: A fű memóriaszíne, általános iskolások (piros) L=76, értelmileg akadályozott diákok (zöld) L*=72, játékfüggő egyetemsiták (kék) L*=19, nem játékfüggő egetemsiták (szürke) L*=64*

75 megfigyelő használta ezt a teszt szoftvert 4 csoportban: 20 átlagos általános iskolás gyermek (8-9 éves), 10 értelmileg, tanulásában akadályozott gyermek (9-15 év közötti), 24 virtuális játékfüggő egyetemi hallgató (átlagéletkor: 20 év) és 21 egyetemi hallgató, akik ritkán vagy soha nem játszanak VR játékkal (átlagéletkor: 20 év). A feladat képek kiszínezése volt a szoftverbe illesztett színpaletta segítségével és néhány kérdés megválaszolása. A kísérletet egy sötét szobában végeztem egy laptop segítségével, amelynek monitorát egy Eye-One készülék kalibrálta. Minden megfigyelőnek jó színlátása volt, Colourlite színteszttel teszteltem őket. A megfigyelők által a kiszínezéshez választott színek adatbázisba kerültek és onnan értékeltem ki az adatokat numerikusan.



5. ábra: Kaukázusi bőrszín memóriaszíne általános iskolások (piros) L=86, értelmileg akadályozott diákok (zöld) L*=71, játékfüggő egyetemsiták (kék) L*=81, nem játékfüggő egetemsiták (szürke) L*=94*

II. <u>TÉZISCSOPORT: Human Computer Interaction és akadálymentes WEB területén</u>: Kutatást végeztem a weblapok akadálymentes tervezésére. Ezekhez ajánlást, tervezési módszert és tesztelési módszert is javasoltam. [10], [11], [12], [13], [14], [30], [31],[36], [66]

<u>II/1. altézis</u>: Módszert javasoltam a WEB és a VR játékok színhelyes tervezésére, hogy a színtévesztők számára ne vesszen el információ és akadálymentesen használhassák azokat. [15], [16], [40], [41], [57], [58]

Korábban nem találtam olyan publikációt, amely foglalkozna a rehabilitációs játékok színének tesztelésével, ezért elvégeztem a StrokeBack [116] projekthez tervezett rehabilitációs játékok színtévesztési tesztelését. Ebben a tesztelésben a vizsgálat fő témája az volt, hogy a különböző színtévesztéssel rendelkezők hogyan érzékelik a játékokat. A vizsgálathoz 4 különféle internetes színtévesztő-szimulátort használtam, ahol képeket lehet feltölteni tesztelésre (ASP.NET) [119], (ETRE) [117], (Coblis) [118] és egy letölthető szoftvert, a ColorOracle-t (ColorOracle) [120] használtam, amellyel teszteltem a képernyőn megjelenő képeket, hogy megtudjam, hogyan néznek ki ezek a különféle színvtévesztéssel rendelkező felhasználók számára (deuteranopia, protanopia, tritanopia). Tesztelésem eredményeként arra a következtetésre jutottam, hogy a helyes színtervezés alapján az objektumok jól láthatóak, tehát a színtévesztő betegek ugyanúgy gyakorolhatnak, mint az ép színlátók.

A magyar egyetemek weboldalait vizsgáltam színhelyességi szempontból a tézishez tartozó második kutatásban. Ennek a kutatásnak a fő célja az volt, hogy megválaszolja azt a kutatási kérdést, hogy a magyar egyetemek weboldalai elérhetők-e azoknak a hallgatóknak, akiknek valamilyen színtévesztési problémájuk van.

Három típusú vizsgálatot végeztem:

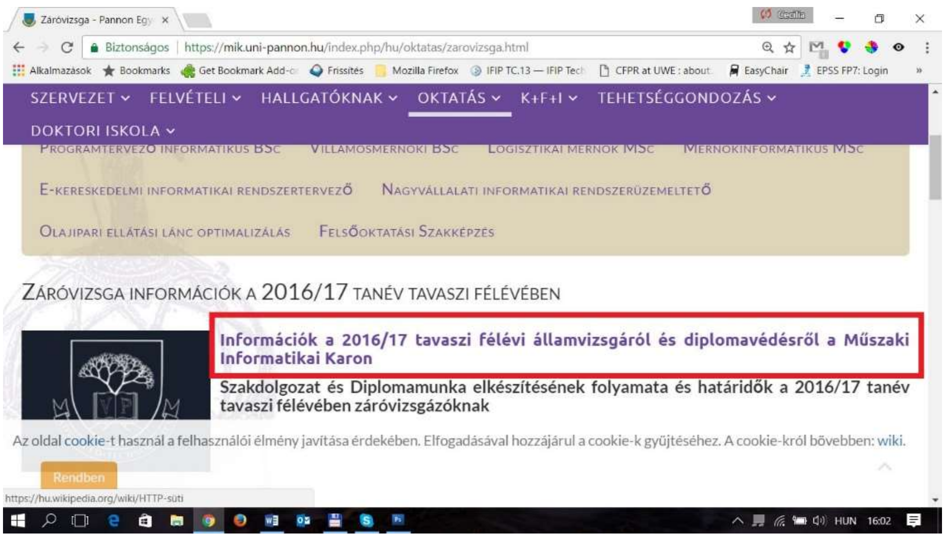
- automatikus tesztelés az AChecker automatikus tesztelővel [121],
- félautomatikus teszt: öt különféle színtévesztő szimulátorral, amelyek elérhetők az interneten, és ahol képeket lehet feltölteni ASP.NET [119], ETRE [117], Coblis [118], valamint letölthető szoftverrel, a ColorOracle-lal [120], amellyel a megjelenő képeket tesztelhetjük a fejlesztői számítógép képernyőjén. Az ötödik a SEE [122] webes alkalmazás volt.
- humán tesztelés a Variantor [123] speciális szemüveggel, valamint kérdőív megválaszolásával.

A kutatás során meghatároztam a magyarországi 64 felsőoktatási intézmény honlapján előforduló leggyakoribb akadálymentességi problémákat a színhelyes tervezés szempontjából. Az 1. táblázat tartalmazza a WCAG 2.0 [109] iránymutatások alapján ismert problémák számát, amelyek szorosan kapcsolódnak a weboldalak láthatóságához.

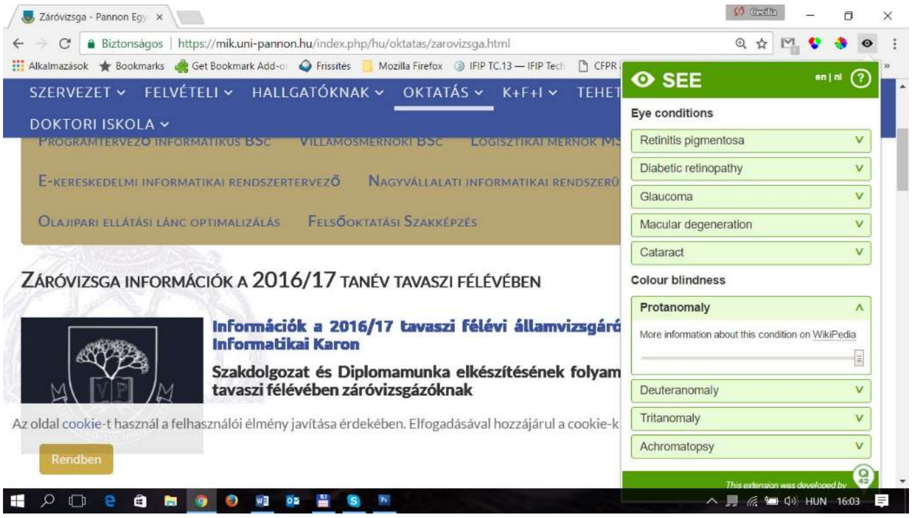
1. táblázat: A WCAG 2.0 által az AChecker használatával megállapított „known” hibák száma

Guidelines	Megfelelőségi követelmény szint	Összes hiba szám	Előfordult legnagyobb hibaszám	Átlag hibaszám
1.1.1 Non-text Content	(Level A)	994	315	15.53
1.4.1 Use of Colour	(Level A)	2	1	0.03
1.4.4 Resize text	(Level AA)	579	77	9.05
1.4.6 Contrast (Enhanced)	(Level AAA)	2164	440	33.81

A 6. ábra tervezési hibát mutat: zavaró színek. „Információk a 2016/2017-es tavaszi félévi államvizsgáról és diplomavédésről…” a fekete-fehér címer jobb oldalán található lila szöveg nagyon hasonló a linkek kék színéhez, azonban ez nem egy link. Ez a világos lila ugyanolyan lila, mint a főmenü sorának háttere és az alatta lévő almenü szövege. A 7. ábra mutatja, hogy mennyire zavaró az, hogy az „Információk a 2016/2017-es tavaszi félévi államvizsgáról és diplomavédésről” szöveg hivatkozásnak tűnik, bár nem link.



6. ábra: Az eredeti weboldal a „záróvizsga” információról.



7. ábra: A „záróvizsga" információinak weboldala, ahogyan azt egy protanóp felhasználó látja

A tesztelés eredményeként arra a következtetésre jutottam, hogy sajnos nem minden magyar felsőoktatási webhely mondható akadálymentesnek a színtévesztési tesztelés alapján. Tehát azon hallgatók vagy jövőbeli hallgatók, akiknek valamilyen színtévesztési porblémájuk van nem tudják az információt ugyanolyan „egyszerű" módon megtalálni, mint az ép színlátók. Azt javaslom, hogy a web-tervezők olyan weboldalakat hozzanak létre, ahol nemcsak a színek szolgáltatnak információkat. Ez azt jelenti, hogy a weboldalakon bizonyos minták vagy nagymértékű kontraszt lenne hatékony a szövegek, gombok és linkek könnyű láthatóságához.

Ezzel a kutatással szerettem volna felhívni az informatikusokat a hiányosságokra, hogy a jövőben javítsák az oktatással kapcsolatos számítógépes játékok és a weboldalak szolgáltatásainak színvonalát. Ebben az esetben a színtévesztéssel rendelkező felhasználók és hallgatók a jövőben gond nélkül használhatják a számítógépes játékokat és a magyar egyetemek weboldalait.

<u>II/2. altézis</u>: Tesztelések alapján meghatároztam a WEB akadálymentességi ajánlások minimális 12 pontból álló szempontrendszerét. Továbbá kidolgoztam egy szakértői kérdőívet a weboldalak tesztelésére. [4], [17], [37], [38], [54], [57], [58], [60]

A kutatás első fázisában riportot készítettem speciális felhasználókkal, majd két szoftver (validator) segítségével készültek a vizsgálatok 12 ország (Amerikai Egyesült Államok, Anglia, Ausztria, Franciaország, Japán, Lengyelország, Magyarország, Németország. Norvégia, Peru, Svájc, Szlovákia) kb. 500 weblapját tesztelve. Az egyik validator a WebXACT [124], a másik a XValid [17], [125] volt. Ezek segítségével 15 kategóriában: kormányzati, oktatási, kereskedelmi, internetes vásárlási, egészségügyi, újságok, TV csatornák, menetrendek, bankok, szabadidő, múzeumok, segítő technológia, tudományos, chat oldalak és sport hírek weblapjai kerültek vizsgálat alá. Az így gyűjtött adatokból átfogó statisztikát készítettem, nemcsak országonként, hanem Európára és Európán kívüli országokra és a 15 kategóriára vonatkozóan is.

A statisztika alapján megállapítottam a leggyakrabban előforduló hibákat, melyek az ajánlásaim alapját képezik. Az összes vizsgált weblap hibáinak statisztikai elemzése után az 50%-os hibahatár feletti hibajelzésekre és figyelmeztetésekre koncentráltam. Megnéztem, hogy melyek ezek a hibaüzenetek, és ennek alapján fogalmaztam meg konkrét technikai (nem szubjektív) ajánlásokat. A következő 10 pontos ajánlásrendszer (ami konkrétabb, mint a WCAG 1.0 [108] illetve WCAG 2.0 [109]) figyelembevételével a vizsgált weblapok minimum 50%-a akadálymentes lenne. Ezek betartása költséghatékony és kevés ráfordított időt igényel.

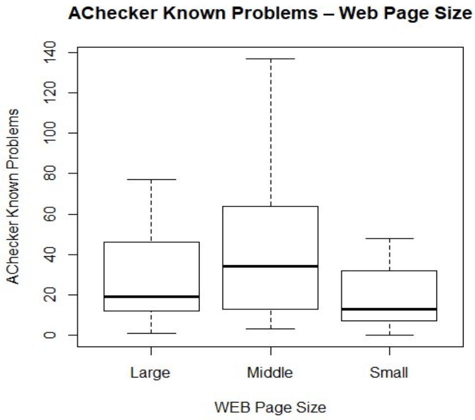
A kutatás második fázisában új méréseket végeztem. A vizsgálatok elsődleges célja az volt, hogy kilenc európai országban megvizsgáljam az egészségügyi ellátással kapcsolatos webhelyeket és azok akadálymentességét felmérjem. Ilyen részletes statisztikai összehasonlítást Európában még nem végeztek, főleg mivel ezen kutatás kettős mérési rendszert kínál, amely kombinálja az automatizált tesztelő szoftver alkalmazását és a felhasználói visszajelzések statisztikai elemzését. A kutatásban 48 kelet-európai webhelyet hasonlítottam össze 51 nyugati és észak-európai webhellyel. A kutatási fázis három lépésben történt, egyrészt az AChecker [121] használatával, másrészt a Nibbler [126] segítségével, majd ezt követően szakértői csoport által kiértékelt felhasználói visszajelzési kérdőívek segítségével. Ezen kutatás célja az volt, hogy meghatározza a leggyakoribb akadálymentességi problémákat és felhívja a webhelyek tulajdonosának figyelmét a hiányosságokra annak érdekében, hogy a jövőben javítsák az egészségügyi ellátással kapcsolatos internetes oldalak szolgáltatásának minőségét. Két további ponttal bővítettem az előző 10 pontos ajánlásomat.

i. **Minden nem szöveges elemhez (pl. képhez) adjunk meg rövid leírást; ha a rövid szöveges leírás nem tudja visszaadni az eredeti információt, akkor hosszú leírást adjunk meg!**
ii. **Abszolút helyett relatív méretezést és pozícionálást használjunk!**
iii. **Az oldal információtartalma az egér használata nélkül is legyen elérhető (ne JavaScript-es eseménykezelőktől/modális ablakoktól függjön a tartalom megjelenítése)!**
iv. **Az űrlapelemek leírása <label> tagekkel történjen, és ahol ez nem lehetséges, használjuk a „title” attribútumot!**
v. **A hivatkozások szövegei szövegkörnyezettől függetlenül legyenek érthetők!**
vi. **A <html> elem rendelkezzen „lang” attribútummal a szöveg elsődleges nyelvének azonosítására, valamint „dir” attribútummal a szöveg írási irányának meghatározására!**
vii. **Minden <table> elemnek legyen „summary” attribútuma, amely leírja a tábla struktúráját és tartalmát!**
viii. **Az egymás mellett szereplő linkek között mindig legyen valamilyen elválasztó karakter!**
ix. **Ellenőrizzük, hogy a weblapok <title> eleme valóban azonosítja-e az adott lapot, utal-e a tartalomra!**
x. **A html elemek legyenek korrektül lezárva, hogy a segítő technológiáknak ne kelljen inkonzisztens szerkezetek javításával foglalkozniuk!**
xi. **Minden webhelyet reszponzívvá kell tenni, hogy bármilyen eszközön vagy platformon optimálisan jelenjen meg, a képernyő méretétől függetlenül.**
xii. **Teszteljen valódi felhasználókkal! Vonja be a fogyatékossággal élőket a kutatási, tervezési és fejlesztési folyamatba. Ez magában foglalja a különböző fogyatékossággal élő emberek bevonását a következők segítségével:**
    - **fókuszcsoportok,**
    - **használhatóság tesztek,**
    - **a tervező és kutatócsoport.**

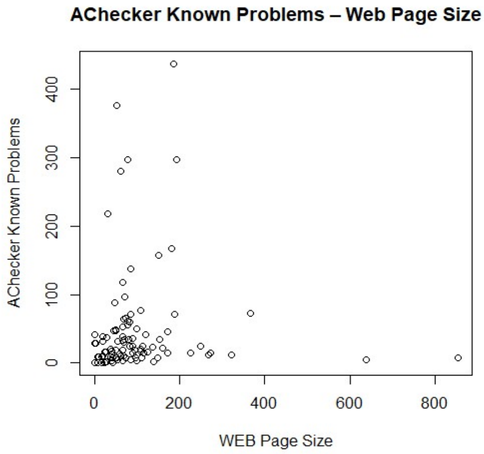
<u>II/3. altézis</u>: Megcáfoltam Goodwin és munkatársai azon tézisét [127], hogy minél gazdagabb egy ország (egy főre jutó GNI), annál kevesebb akadály jelenik meg webhelyein és minél nagyobb a weboldal mérete Kbyte-ban, annál több akadály jelenik meg az oldalon. Tehát megmutattam, hogy az akadálymentesen hozzáférhető weboldalak kialakítása független a gazdasági helyzettől és a weboldalak méretétől, valamint a demográfiai igényektől is. [4]

A fenti kutatásban a vizsgált európai webhelyek kelet európai és észak-nyugat európai országokba lettek csoportosítva. Az eredmények különféle szemszögből lettek összehasonlítva és megmutattam, hogy a két csoport között nem lehet szignifikáns különbséget megállapítani a gazdasági helyzetükre alapozva. Ugyanígy nem figyelhető meg korreláció a weboldalak méretének kilobájtban, az akadályok számával történő összehasonlításakor. Továbbá, nincs szignifikáns korreláció a szoftver tesztek eredményei és az idős emberek aránya között az adott országban.

A 8. és 9. ábra azt mutatja, hogy az AChecker teszt esetén a nagyobb méret nem jelent tendenciájában több hibát. A korrelációs együttható becsült értéke 0,027, ez nagyon közel áll a 0-hoz. A próba során számolt p-value értéke 0,791, ezért elfogadjuk azt a hipotézist, hogy ezek a mennyiségek nem korrelálnak. Ez az eredmény ellentétes azzal, amit Goodwin et al. [127] állított.

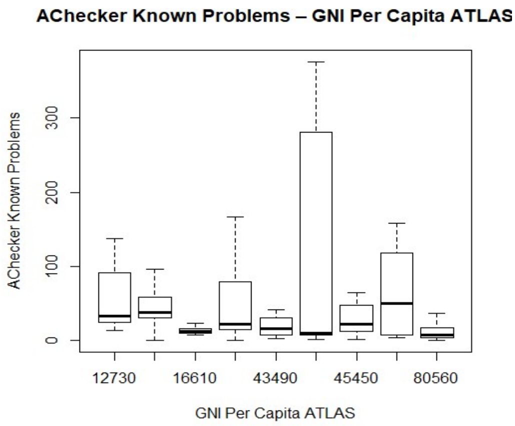


8. ábra: Az AChecker által ismert értékek box-plot diagramja a weboldalméret függvényében (nagy, közepes, kicsi)



9. ábra: Az AChecker ismert értékeinek diagramja a weblap méretének függvényében (Kbyte-ban)

A 10. ábra mutatja az AChecker által ismert, az egy főre jutó GNI függvényében ismertetett hibák számát. A korrelációs együttható becsült értéke szerint -0,097, tehát a függetlenség 0,169 szignifikanciaszinten elfogadható.



10. ábra: Az AChecker által ismert problémák box-plot diagramja az egy főre jutó GNI függvényében

III. <u>TÉZISCSOPORT: Egyetemes tervezés az egészségügyi informatika területén</u>: Kutatást végeztem mind a multimédiás, mind VR játékok akadálymentes tervezésére. Ezekhez ajánlást, tervezési módszert és tesztelési módszert is javasoltam. Az előző téziscsoport ajánlásai alapján bebizonyítottam, hogy lehet akadálymentes weboldalt létrehozni.

III/1. altézis: Megalkottam a készségfejlesztő és rehabilitácis célú multimédiás és VR játékok a felhasználói igényeknek megfelelő személyre szabhatóságának tervezési követelményeit és tesztelési módszerét. [2], [15], [18-24], [39], [44-53]

Az elmúlt két évtizedbeli játékfejlesztéseknél és a GOET [128] projekt keretében lehetőségünk volt több multimédiás és VR játékot fejleszteni értelmileg akadályozott fiatalok önálló életvitelének segítésére. A játékok fejlesztéséhez először fel kellett mérni a felhasználói igényeket, mind pedagógia szempontból, mind a felhasználói felület tervezése szempontjából is. A többszörös tesztelések során alkottam meg tesztelési szempontrendszeremet. A GOET projektben pedagógiai teszteléseket nemcsak Magyarországon, hanem a partnerországokban (Anglia, Belgium, Litvánia) is elvégeztük. Az értelmileg akadályozott diákoknak 6 héten át hetente kétszer kellett minimum 20 percet játszaniuk a szoftverekkel. A használhatósági (usability) vizsgálathoz pedig humán kérdőívet készítettem, ami 40 kérdést tartalmazott. Ezt a speciális iskolák, oktatói, szülői csoportok és szakértők töltötték ki azon iskolákban, amelyekben a pedagógiai vizsgálatok is készültek. A GOET projektben [128] elért kutatási eredmények jól haszálhatóak voltak az ISG4Competence projektben [129] is.

2004-től kezdve fejlesztettünk több projekt keretében rehabilitációs szoftvereket stroke pácienseknek. Majd a StrokeBack [116] projekt keretében több VR és multimédia alapú játékot, motivációs és tanító animációt fejlesztettünk. Ezek létrehozásához nemcsak a terapeuták, hanem a páciensek speciális igényeit és képességeit is figyelembe kellett venni. A telemedicina rendszer számára készített rehabilitációs játékok fejlesztése alapján rájöttem, hogy a hagyományos szoftverfejlesztési modellek nem alkalmazhatók. Ezért új szoftverfejlesztési módszert hoztam létre a betegek és a terapeuták igényeit figyelembe véve, végül a következő követelményrendszert hoztam létre:

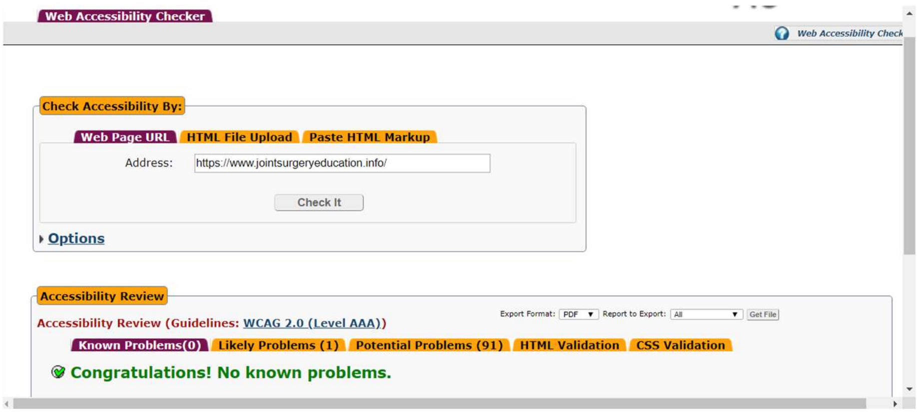
- **Funkcionális követelmények:**
    - a pontozási renszer ne legyen negatív, motiválja a pácienst,
    - oktató animációk mutassák be a gyakoroltatni kívánt mozgást minden egyes játék előtt,
    - a gyakoroltatni kívánt feladatról és mozgásról a visszajelzés teljesen világos és egyértelmű legyen,
    - a játékokban lehessen több téma közül választani,
    - minden egyes játék után a témához tartozó motivációs animáció fusson,
    - pályaszerkesztő segítségével lehessen személyre szabni a játékot.

- **Nem-funkcionális követelmények:**
    - minden játék egy keretrendszerben fusson, ami bővíthető legyen,
    - a játékok struktúrájukban és stílusukban passzoljanak egymáshoz,
    - a korábban megírt elemeket fel lehessen használni a keretrednszerben a redundancia elkerülésére.

<u>III/2. altézis</u>: Bebizonyítottam, hogy az akadálymentességi tervezési ajánlásaim alapján létrehozható egészséggel foglalkozó akadálymentes weboldal, továbbá az ilyen weblapok használata segíti az ápolói munkafolyamatot, a hatékonyságot és a páciensek oktatását. [29]

A webhelyeknek a betegek oktatására történő használata egyre gyakoribb. Bebizonyosodott, hogy a megfelelően végrehajtott és hatékony preoperatív páciens oktatási beavatkozás előnyei javítják a műtéten átesett betegek pszichológiai és fizikai jólétét. E kísérleti tanulmány célja az volt, hogy meghatározzuk egy weboldal használhatóságát, hasznosságát és megvalósíthatóságát, amelyet azért hoztunk létre, hogy növeljük a betegek elkötelezettségét és javítsuk a preoperatív oktatás színvonalát a csípő- és térdprotézis műtét előkészítése során. Nyolcvan 40 és 65 év közötti beteg vett részt a felmérésben, ezek közül 52,5% volt nő, 71,25% -ot térdpótlás, 28,75% -ot csípőpótlás miatt operáltak. Negyven beteg véletlenszerűen került be a papír alapú oktatási csoportba, a többi 40 pedig a papír és a weboldal alapú oktatási csoportba. Mindegyik csoportból azonban csak 19 fő vett részt a kérdőíves vizsgálatban. A felmérésben szerepeltek a betegek ismeretére, az oktatási anyaggal kapcsolatos elégedettségére, hasznosságára és használhatóságára vonatkozó kérdések és azok kiértékelésének kvalitatív adatai, amelyeket a Perceived Health Website Usability Questionnaire online felmérés alapján lettek kiértékelve. A papír alapú felmérés tíz kérdést tartalmazott egy 7-pontos Likert skálán, míg a web-alapú felmérés tizennégy kérdést tartalmazott ugyanazon a 7 pontos Likert-skálán. Leíró statisztikákat és független minták t-próbáit használtuk a szokásos papíralapú oktatási és weboldal-oktatási csoportok összehasonlító elemzéséhez. Az eredmények kiszámításához a Microsoft Excel adatelemző eszközt alkalmaztuk. A szignifikancia szintet 0,05-re állítottuk a kiértékeléseknél. A vizsgálat eredménye nem mutatott statisztikailag szignifikáns különbséget mindkét csoportban a 0,05 szintnél. Az ápolószemélyzetre vonatkozó felmérés eredményei szerint a weboldal használata javította az ápolói munkafolyamatot, a hatékonyságot és a betegek oktatását.

A 11. ábra szemlélteti a vizsgálatban használt weboldal akadálymentességi tesztelését az AChecker [121] használatával.



11. ábra: Az AChecker automatizált teszt eszköz használatának képernyőképe

IV Az eredmények alkalmazása

Kutatásomban arra törekedtem, hogy eddig megoldatlan vagy újonnan felmerülő problémákat, kérdéseket vizsgáljak és javaslatokat tegyek azok megoldására.

Programtervező matematikusként mindig érdekelt, hogy az általam készített szoftver vajon mennyire használható mások számára. Ebbe nemcsak a funkciókat értem, hanem a felhasználói interfész tervezését is. Közben Schanda János professzor úr irányításával sok mindent megtanultam a színekről és elkezdtek érdekelni a színtani kutatások. Arra is rájöttem, hogy a speciális felhasználói csoportoknak kezdetekben alig fejlesztettek számukra használható szoftvereket, így érdeklődésem kibővült az akadálymentes tervezés területével.

Tudományos hozzájárulásaim elsősorban a következőkben felsorolásra kerülő nemzetközi, az Európai Unió által finanszírozott projekteket érintették, melyek mindegyikének hazai projektvezetője voltam.

A "Colour Research for European Advanced Technology Employment" CREATE (MSCF-CT-2006-045963) projekt [130] elsősorban a jövő szakembereinek, kutatóinak a színtan területén történő képzését, továbbképzését szolgálta mind az alapképzés, mind a PhD képzés területén. Ebben a projektben többször tartottam a félévente Európa különböző országaiban megrendezésre kerülő képzéseken előadásokat. A pojekt zárása után számos szakkönyv született, melyet Európa különböző egyetemein használnak a színtan oktatásában. Hozzájárulásom konkrétan az I/1., I/2. és a II/1. tézisekben részletesen ismertettem, kutatási eredményeim lényeges szerepet kaptak azon könyvekben, melyekbe a könyvek szerkesztői meghívtak. [56-59]

A "Design for All for eInclusion" DfA@eInclusion 033838 projektben [131] több munkacsoportban is aktívan dolgoztam. A II/1. tézisben és a II/2. tézis első kutatásában részletesen megtalálhatóak azok a tudományos eredmények, melyek itt hasznosultak, elsősorban a „Standaradisation" és a „Technological Development" munkacsomagokban. Ennek a projektnek nemcsak a hazai témavezetője voltam, hanem a 23 ország részvételével megvalósuló nemzetközi pojekt utolsó évében a koordinátora is. Ezen erőfeszítés eredményeként született meg az általam szerkesztett könyv is „Principles and Practice in Europe for e-Accessiblity" címmel disszeminációs tevékenységként. [70]

A DfA projekttel párhuzamosan hazai témavezetőként dolgoztam a web_access "Joint Programme on Accessible Web Design" (133818-LLP-1-2007-1-AT-ERASMUS-ECDEM) projektben [132]. A projekt keretén belül 5 nyugat-európai egyetemmel közösen kidolgoztunk egy 120 kredites Blended-learning képzést az akadálymentes webtervezés és segítő technológiai oktatás elősegítésére. Ebben a projektben is felhasználásra kerültek a II/2. tézisem első kutatásában részletesen leírt eredmények. A nemzetközi projekt zárása után a Pannon Egyetem számára kidolgoztam a 60 kredites „Akadálymentes webtervező" és az ugyancsak 60 kredites „Segítő technológiai" szakmérnök szakokat, melyeket sikresen akreditáltak.

Nem lehet kellőképpen hangsúlyozni, mennyire fontos, hogy az eredmények jelentős része folyamatosan hasznosult és hasznosul a gyakorlatban. A kutatásaim eremdényeként számos, az egyetemi hallgatói kutatócsoportommal közös fejlesztésünk is készült (GOET, StrokeBack, ISG4Competence projektek) [128], [116], [129], ezeket a projektek keretében résztvevő partnereink használják hazánkon kívül Európa 9 országában. Mindezen fejlesztések a disszertációban részletesen ismertetett III/1. tézisen alapultak.

Ugyancsak a III/1.tézis alapján született publikációk eredményeképpen hívtak meg a LUDI - TD COST Action TD1309 – „Play for Children with Disabilities" nemzetközi konzorciumba [133]. A tavaly zárult nemzetközi projektben Management Committee tag is voltam. A projekt során közvetlenül hasznosultak az I/1. az I/2. és a III/1. tézisbeli eredményeim. Ezen nemzetközi projektemet az akkori PhD hallgatómmal közösen írt „Play for children with disabilities: some reflections on the results on the users' needs and on the role of technologies" című könyvfejezettel zártam. [67]

A III/2 tézis pedig még jobban alátámasztja a II/1. és II/2. tézisben elért kutatási eredményeimet. A III/2. tézisbeli állítást egy baltimori (USA) közkórház egészségügyi személyzete és páciensei által kitöltött kérdőív statiszikai elemzése is igazolja. [29]

A jelen disszertáció benyújtásának idején induló nemzetközi projektben is nemcsak hazai projektvezető, hanem Management Committee tag vagyok: (COST CA19104) „Advancing Social inclusion through Technology and Empowerment". [134] Ezen tématerület is jelentős átfedésben van mind a színtan, mind az akadálymentes tervezésbeli kutatásaimmal.

Mind a színtervezés, mind az akadálymentes tervezés területén olyan új eredményeket értem el, amikre számos hivatkozást kaptam. A tézisek jól használhatók akadálymentes multimédiás és VR játékok tervezéséhez és teszteléséhez, valamint akadálymentes honlapok készítéséhez és usability teszteléséhez.

A kutatásaim jól használhatók az oktatásban is. Az eredményeimet tekintve számos alkalommal voltam meghívott előadó nemzetközi konferenciákon. Különösen fontos, hogy kutatásaimat nemzetközileg elismerik, ezért is rendezhettem meg az Association for the Advancement of Assistive Technology in Europe (AAATE) [135] konferenciát 2015-ben Magyarországon, és jelenleg is számtalan felkérést kapok nemzetközi pályázatok és folyóirat cikkek bírálatára.

V Egyetemi oktatói és publikációs munkák

Az elsősorban a Pannon Egyetemhez kötődő kutatói és oktatói tevékenységem mellett meghívott előadó voltam a Pázmány Péter Katolikus Egyetem (PPKE) Információs Technológiai és Bionikai Karán, ahol a „Felhasználói interfészek tervezése” tantárgyban tartottam órákat szakmérnök képzésen. Rendszeres meghívott előadója vagyok a Budapesti Műszaki és Gazdaságtudományi Egyetem és az Óbudai Egyetem rehabilitációs mérnök szakképzésében.

Habilitációs pályázatomat a Pannon Egyetemen védtem meg 2017-ben.

Oktatói tevékyenységem alatt 3 Ph.D., 111 M.Sc., 93 B.Sc., 53 TDK dolgozat és 14 Innovációs verseny pályamunka témavezetője voltam. Egyetemi és doktori hallgatóim számos díjat nyertek.

1998-tól 10 éven át titkára voltam Magyar Tudományos Akadémia Veszprémi Területi Bizottságának Alkalmazott Fény- és Színtani Munkabizottságának, valamint rendszeres előadója voltam a bizottság által szerevezett workshopoknak, konferenciáknak.

2009-ben megalapítottam a Neumann János Számítógéptudományi Társaság (NJSZT) „Human-Computer Interaction & Design for All” Szakosztályát, melynek elnöke voltam 10 évig, majd átadtam az elnökséget végzett doktorandusz hallgatómnak, azóta a szakosztály alelnöke vagyok. Szakmai tanácsadója vagyok az NJSZT „Multimédia az Oktatásban” Szakosztálynak. Valamint aktív tagja vagyok az NJSZT „Orvos-biológiai” Szakosztályának. Mindhárom szakosztály által megrendezett konferenciáknak évenkénti rendszeres előadója vagyok. Publikcióim szorosan kapcsolódnak a bemutatott téziseimhez.

VI Köszönetnyilvánítás

Különösen hálával tartozom †Liszi János professzor úrnak, aki az első doktorim témavezetője volt. Köszönöm †Dr. Vass József volt tanszékvezetőmnek, aki megbízott azzal, hogy multimédiával foglalkozzam. Végtelen hála illeti †Schanda János professzor urat, akitől a színtani kutatásokhoz szükséges ismereteket tanulhattam és akinek a laboratóriumában dolgozhattam majdnem két évtizedig. Hálás vagyok azért a kutatói szabadságért, amit számomra biztosított.

Köszönöm munkatársaim, kollégáim támogatását, különösen Dr. Mihálykóné Dr. Orbán Éva statisztikai számításokban adott szakmai tanácsait.

Kösszönet illeti a témavezetett B.Sc., M.Sc. hallgatóimat szorgalmas munkájukért és köszönöm a szakdolgozatuk, diplomamunkájuk keretében készített szoftvereket. Külön köszönöm a Ph.D. hallgatóim munkáját.

Nagy hálával tartozom a magyarországi speciális iskolák gyógypedagógusainak és a rehabilitációs intézetek szakembereinek hasznos tanácsaikért. Nagyon sokat tanultam tőlük. Minderre a tudásra a mai napig támaszkodhatom egy-egy újabb szoftver tervezésekor.

Hálás vagyok a különböző kutatási feladatokat támogató Európai Uniós projektek keretében megismert kutatóknak, oktatóknak. Ezúton is köszönöm Pier Luigi Emiliani emeritus professzornak, az Institute of Applied Physics “Nello Carrara” (IFAC) volt igazgatójának, hogy életem első FP6-os projektjébe meghívott a publikációim alapján. Köszönöm az utóbbi évek közös orvosinformatikai kutatásait Dr. Kelemen Árpádnak a Unversity of Mariland egyetem professzorának.

A disszertációban bemutatott munkát a Pannon Egyetemen túl nemcsak a 4. fejezetben részletezett különböző projektek támogatták, hanem az akadálymentességi kutatáshoz különösen hozzájárult a King Salman Center for Disability Research [136] által adományozott “King Salman Award for Disability Research” díj. Ezenkívül köszönöm az Association for the Advancement of Assistive Technology in Europe nemzetközi szervezet által adományozott “AAATE-Diamond-Award” díjat, mely erkölcsi támogatást biztosított.

Végtelenül hálás vagyok az egész családomnak, férjemnek, gyerekeimnek és családjaiknak, hogy türelmesek voltak és minden lehetséges módon támogattak.

„Úgy érezzük, hogy amit teszünk, csak csepp a tengerben.
Anélkül a csepp nélkül azonban sekélyebb volna a tenger.”
Teréz Anya

Appendix C
Author's contribution

This appendix contains a table. This table is the detailed lists of the publications where my contribution of this dissertation is clearly indicated.

Thesis group number	publication number	number and position of co-authors	my contribution %	type of publication
I	9	0	100 %	journal
	34	1 professor 2 B.Sc. students	>75%	conference proceedings
	35	0	100 %	conference proceedings
	56	0	100 %	book chapter
	57	0	100 %	book chapter
	58	0	100 %	book chapter
	59	0	100 %	book chapter
II	4	1 associate professor	>75 %	journal
	15	1 senior lecturer 1 technical assistant 1 Ph.D. student	>80 %	journal
	16	1 Ph.D. student	>90 %	journal
	17	2 B.Sc. students	>75 %	journal
	37	3 B.Sc. students	>75 %	conference proceedings
	38	2 B.Sc. students	>80 %	conference proceedings

	40	3 M.Sc. students	>70 %	conference proceedings
	41	0	100 %	conference proceedings
	54	0	100 %	conference proceedings
	57	0	100 %	book chapter
	58	0	100 %	book chapter
	60	0	100 %	book chapter
III	2	3 M.Sc. students	>80 %	journal
	15	1 senior lecturer 1 technical assistant 1 Ph.D. student	>80 %	journal
	18	1 psychologist 2 M.Sc. students	>50%	journal
	19	4 M.Sc. students	>75 %	journal
	20	2 M.Sc. students	>80 %	journal
	21	1 Neurolinguistics 2 M.Sc. students	>75 %	journal
	22	2 professors 2 technical assistants	>80 %	journal
	23	2 engineers with Ph.D..	>50 %	journal
	24	1 Ph.D. student	>90 %	journal
	29	2 professors 2 M.Sc. students	>50 %	journal
	39	1 psychologist 3 M.Sc. students	>80 %	journal
	44	3 M.Sc. students	>80 %	conference proceedings
	45	1 Ph.D. student 1 M.Sc. student 1 technical assistant	>80 %	conference proceedings

	46	1 professor 1 Ph.D. student 4 technical assistants	>80 %	conference proceedings
	47	1 Ph.D. student 1 B.Sc. student	>80 %	conference proceedings
	48	2 professors 1 associate professor 3 Ph.D. students 2 technical assistants	>60 %	conference proceedings
	49	2 professors 1 M.Sc. students 1 B.Sc. students	>50 %	conference proceedings
	50	2 professors 4 M.Sc. students 3 B.Sc. students	>70 %	conference proceedings
	51	2 B.Sc. students	>90 %	conference proceedings
	52	2 B.Sc. students	>90 %	conference proceedings
	53	2 professors 4 M.Sc. students 3 B.Sc. students	>70 %	conference proceedings

References

The author's journal publications

[1] **Sik Lányi, C.**, Kosztyán, Zs., Kránicz, B., Schanda, J., Navvab, M. Using multimedia interactive e-teaching in color science. *LEUKOS* The Journal of the Illuminating Engineering Society of North America. **4**(1): 71-82. (2007) ISSN1550-2724, (**IF=0.250**)

[2] **Sik Lányi, C.**, Bacsa, E., Mátrai, R., Kosztyán, Zs. Developing interactive multimedia rehabilitation software for treating patients with aphasia. *International Journal on Disability and Human Development*, Special issue on disability, virtual reality and associated technologies. **4**(3):225-229. (2005) ISSN 1565-012X

[3] Mátrai, R., Kosztyán, Zs. T., **Sik Lányi, C.** Navigation methods of special needs users in multimedia systems, *Computers in Human Behavior*. **24**(4):1418-1433. (2008) (**IF=0.808**)

[4] **Sik-Lanyi, C.**, Orbán-Mihálykó, É. Accessibility Testing of European Health-Related Websites. *Arabian Journal for Science and Engineering (Arab J Sci Eng),* 2019, **44(11)**:9171-9190 https://doi.org/10.1007/s13369-019-04017-z (**IF=1.711**)

[5] Szalmás, A., Bodrogi, P., **Sik Lányi, C.** Characterizing luminous efficiency functions for a simulated mesopic night driving task based on reaction time, *Ophthalmic and Physiological Optics*, 2006. **26**: 281-287. ISSN 0275-5408, (**IF=1.483**)

[6] **Sik Lányi, C.**, Schanda, J. Analysing the Colours of the Virtual Reality Museum's Picture, *Acta Polytechnica Hungarica*, 2011, **8**(5):137-150, ISSN: 1785-8860, (**IF: 0.385**), http://www.uni-obuda.hu/journal/Issue31.htm

[7] Szucs, V., **Sik-Lányi, C.** Color Rendering of Images in the Internet and Print Reproductions of the Sistine Chapel's Frescos, *LEUKOS*, 2016, **12**(1-2) SI:101-110 online 00: 1-10, 2016, ISSN: 1550-2724 print / 1550-2716 online (**IF=0.958**)

[8] **Sik-Lanyi, C.**, Szucs, V., Hirschler, R. Coloured shadows—Why they can be photographed, *Color Res Appl.* 2019; **44(6)**: 859-874, published online: 9 August 2019 https://doi.org/10.1002/col.22420 (**IF=1.027**)

[9] **Sik Lanyi, C.** Styles or Cultural Background does Influence the Colors of Virtual Reality Games? *Acta Polytechnica Hungarica*. **11**(1): 97-119. (2014) ISSN: 1785-8860, (**IF=0.471**)

[10] **Sik Lányi C.**, Lányi, Zs. Multimedia Program for Training of Vision of Children with Visual Impairment and Amblyopia. *Journal of Information Technology Education*. **2**:279-290. ISSN: 1539-3585 (2003) http://www.jite.org/documents/Vol2/v2p279-290-28.pdf

[11] **Sik Lányi, C.**, Lányi, Zs., Tilinger, Á., Using Virtual Reality to Improve Space and Depth Perception. *Journal of Information Technology Education*. **2**:291-304. (2003) ISSN: 1539-3585 http://www.jite.org/documents/Vol2/v2p291-303-27.pdf

[12] **Sik Lányi, C.**, Tilinger, Á. Developing virtual environments for rehabilitation of autistic children. *International Journal of Rehabilitation Research*. **27**(1):123. (2004) ISSN 0342-5282 (**IF=0.358**)

[13] **Sik Lányi, C.**, Mátrai, R., Molnár, G., Lányi, Zs. User Interface Design Question of Developing Multimedia Games and Education Programs for Visual Impairment Children. *Special Issue of Elektrotechnik & Informationstechnik (e&i)* by Springer Wien/New York,"Technology Enhanced Learning (TEL)", (12):488-494. (2005) ISSN 0932-383X

[14] **Sik Lányi, C.**, Mátrai, R., Tarjányi, I. Analysing the navigation of mentally impaired children in virtual environments. *International Journal on Disability and Human Development, Special issue on disability, virtual reality and associated technologies*. **5**(3): 217-221. (2006) ISSN 1565-012X

[15] Szücs, V., **Sik Lanyi, C.**, Szabo, F., Csuti, P. Colour-check in stroke-rehabilitation games, J *Altern Med Res* 2017;**9**(2):7 pages. ISSN: 1939-5868, Nova Science Publishers, Inc.: https://www.novapublishers.com/catalog/product_info.php?products_id=61590

[16] **Sik-Lanyi, C.**, Szucs, V. Are the WEB-pages of the Hungarian Universities Accessible for Students with Color Deficiency? *Óbuda University e-Bulletin*, 2018, **8**(2):53-58. http://uni-obuda.hu/e-bulletin/Sik-Lanyi_Szucs_13.pdf

[17] Czank, N., Sik, A., **Sik Lányi, C.** Testing the Accessibility of WEB Sites. *International Journal of Knowledge and Web Intelligence* (IJKWI). **2**(1): 87-98. (2011)

[18] Pataky, I., **Sik Lányi, C.**, Szabó, J., Páll, A. Development of a computer controlled cognitive diagnostics and rehabilitation method. *Clinical Neuroscience/Ideggyógyászati Szemle*. **56**(7-8):74-75. (2003)

[19] **Sik Lányi, C.**, Geiszt, Z., Károlyi, P., Tilinger, Á., Magyar, V. Virtual Reality in special needs early education. *The International Journal of Virtual Reality*. **5**(4):55-68. (2006) ISSN1081-1451

[20] **Sik Lányi, C.**, Geiszt, Z., Magyar, V. Using IT to Inform and Rehabilitate Aphasic Patients. *Informing Science Journal*. 9:163-179 (2006) ISSN: 1521-4672 http://inform.nu or directly at http://inform.nu/Articles/Vol9/v9163-179SikLanyi67.pdf

[21] **Sik Lányi, C.**, Stark, J.A., Kamson, M.E., Geiszt, Z. Do we need high-scale flexibility in virtual therapies? *International Journal on Disability and Human Development, Special issue on disability, virtual reality and associated technologies*. **5**(3): 251-256. (2006) ISSN 1565-012X

[22] **Sik Lanyi, C.**, Brown, D., Standen, P., Lewis, J., Butkute, V. Results of user interface evaluation of serious games for students with intellectual disability. *Acta Polytechnica Hungarica*. **9**(1):225-245. (2012), (**IF=1.286**)

[23] Ortmann, S., Langendörfer, P., **Sik Lányi, C.** Telemedical assistance for ambulant rehabilitation of stroke patients. 9th World Congress on Brain Injury, Edinburgh, Scotland, March 21-25, 2012, *BRAIN INJURY* **26**(4-5):644-645. (2012) (**IF=1.513**)

[24] **Sik Lanyi, C.**, Szucs, V. Games applied for therapy in stroke tele-rehabilitation. *International Journal of Stroke*. **9**(Suppl. S3):300, October 2014 (WSC-1477) (**IF=4,029**)

[25] **Sik Lanyi, C.**, Szucs, V., Stark, J. Virtual reality environments development for aphasic clients. *International Journal of Stroke*. **9**(Suppl. S3) pp:241, October 2014 (WSC-1510) (**IF=4,029**)

[26] Yates, M., Kelemen, A., **Sik Lanyi, C.** Virtual reality gaming in the rehabilitation of the upper extremities post-stroke. *Brain Injury*. **30**(7):855-863, DOI: 10.3109/02699052.2016.1144146, published onle: 30 March 2016. (**IF=1.665**)

[27] **Cecilia, Sik-Lanyi**, Szucs, V., Shirmohammadi,S., Grudeva, P., Abersek, B., Guzsvinecz, T., Van Isacker, K. How to Develop Serious Games for Social and Cognitive Competence of Children with Learning Difficulties, *Acta Polytechnica Hungarica*, 2019, **16**(6)**:**149-169. http://www.uni-obuda.hu/journal/SikLanyi_Szucs_Shirmohammadi_Grudeva_Abersek_Guzsvinecz_VanIsacker_93.pdf (**IF=1.286**)

[28] Flogie, A., Abersek, B., Kordigel Abersek, M., **Sik-Lanyi, C.** Intelligent Serious Games for Children with Learning Difficulties, *JMIR Serious Games*, (**IF=3.351**) JMIR Serious Games 2020 | vol. 8 | iss. 1 | e13190

[29] Dayucos, A., French, L.A., Kelemen, A., Liang, **Y., Sik Lanyi, C.** Creation and Evaluation of a Preoperative Education Website for Hip and Knee Replacement Patients—A Pilot Study, *Medicina*, 2019, **55(2)**, 32. https://doi.org/10.3390/medicina55020032 (**IF= 1.467**)

The author's selected international conference publications

[30] **Sik Lányi, C.**, Váry, Á., Sik, A., Nemetz, A., Geiszt, Z. Multimedia Programs for Children with Hearing Difficulties, *Lecture Notes in Computer Science*. LNCS 3118, ICCHP 2004, Springer Verlag Berlin-Heidelberg, pp: 14-21. ISSN 0302-9743, (**IF=0.513**)

[31] **Sik, Lányi C.**, Tilinger, Á. Multimedia and Virtual Reality in the Rehabilitation of Autistic Children, *Lecture Notes in Computer Science*. LNCS 3118, ICCHP 2004, Springer Verlag Berlin-Heidelberg, pp: 22-28. ISSN 0302-97439, (**IF=0.513**)

[32] **Sik Lányi, C.**, Magyar V. Wireless communicator for patients in intensive care, *Lecture Notes in Computer Science*, LNCS 4061, ICCHP 2006, Springer Verlag Berlin-Heidelberg, pp: 508-515. ISSN 0302-97439 (**IF=0.513**)

[33] Geiszt, Z., **Sik Lányi, C.** A Fully Adjustable Virtual Classroom, *Lecture Notes in Computer Science*, LNCS 4061, ICCHP 2006, Springer Verlag Berlin-Heidelberg, pp: 823-830. ISSN 0302-97439 (**IF=0.513**)

[34] **Sik Lanyi, C.**, Sik, A., Sik, G., Schanda J. Colour Fidelity in Reproductions and Popular Images, *AIC* 2008 Colour – Effects & Affects, Colour and education: Ideas, inspiration, examples.15-18 June 2008 in Stockholm, Sweden pp. 211-212.

[35] **Sik Lányi, C.** Investigating of Memory – Colors of Intellectually Disabled Children and Virtual Game Addict Students. *Lecture Notes in Computer Science*, LNCS 5889, USAB 2009, Springer Verlag Berlin-Heidelberg, pp. 463-475. ISSN 0302-9743. DOI: 10.1007/978-3-642-10308-7

[36] **Sik Lányi, C.**, Galyas, L. Developing Multimedia-Game Software to Improve Space and Depth Perception. *Lecture Notes in Computer Science*, LNCS 5105, ICCHP 2008, Springer Verlag Berlin-Heidelberg, pp. 827-834. ISSN 0302-9743

[37] **Sik Lanyi, C.**, Forrai, S., Czank, N., Hajgató, A. On Developing Validator Software XValid for Testing Home Pages of Universal Design. *Universal Access in HCI*, PART I, HCII 2007, *Lecture Notes in Computer Science*, LNCS 4554, pp. 284-293.

[38] **Sik Lányi, C.**, Nagy, E., Sik, G. Accessibility Testing of a Healthy Lifestyles Social Network. *Lecture Notes in Computer Science*, K. Miesenberger et al. (Eds.): ICCHP 2012, Part I LNCS 7382, Springer Verlag Berlin-Heidelberg, pp: 409-416, 2012.

[39] **Sik Lányi, C.**, Bacsa, E., Mátrai, R., Kosztyán, Zs., Pataky, I. The Design Question of Development of Multimedia Educational Software for Aphasia Patients. *Lecture Notes in Computer Science*, LNCS 3118, ICCHP 2004, Springer Verlag Berlin-Heidelberg, pp: 6-13. ISSN 0302-9743, (**IF=0.513**)

[40] **Sik Lányi, C**, Szűcs, V, Dömők, T, László, E Developing serious game for victims of stroke, Proc. 9th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies, ICDVRAT 2002, (P.M. Sharkey, E. Klinger Eds), Laval, pp. 503-506.

[41] **Sik-Lanyi, C.** Colour-check on websites of the Hungarian universities, 6th Colour Specialist International Conference in Hungary, Interenational Interdisciplinary Conference on Colur and Pattern Harmony, pp. 35, Pápa, Hungary, 21-23 May, 2017.

[42] **Sik Lányi, C.**, Brown, D.J. Design of serious games for students with intellectual disability, *bcs* Electronic Workshop in Computing (eWiC), India HCI 2010, Bombay, India, March 20-24, 2010, pp. 151-160. http://www.bcs.org/server.php?show=conWebDoc.35773

[43] **Sik Lányi, C.**, Brown, D.J., Standen, P., Lewis, J., Butkute, V. User interface evaluation of serious games for students with intellectual disability. *Lecture Notes in Computer Science*, LNCS 6179, ICCHP 2010, Part 1, Springer Verlag Berlin-Heidelberg, pp: 227-334, DOI: 10.1007/978-3-642-14097-6

[44] Dömők, T., Szűcs V., László E., **Sik Lányi C.** “Break the Bricks” Serious Game for Stroke Patients. *Lecture Notes in Computer Science*, K. Miesenberger et al. (Eds.): ICCHP 2012, Part I LNCS 7382, Springer Verlag Berlin-Heidelberg, pp: 673-680, 2012

[45] Guzsvinecz, T., Szücs, V., Paxian S., **Sik Lanyi, C.** Android games for developing fine coordination of movement skills, K. Miesenberger et al. (Eds.): ICCHP 2016, Part II, *LNCS 9759*, pp: 549-552, Springer International Publishing Switzerland, 2016, DOI: 10.1007/978-3-319-41267-7_77

[46] Paxian, S., Szücs, V., **Sik-Lanyi, C.**, Shirmohhamadi, S., Abersek, B., Lazarov, A., van Isacker, K. Target group questionnaire in the “ISG for Competence” project, K. Miesenberger et al. (Eds.): ICCHP 2016, Part II, *LNCS 9759*, pp: 317-320, Springer International Publishing Switzerland, 2016, DOI: 10.1007/978-3-319-41267-2_44

[47] Godár, M., Szücs, V., **Sik-Lanyi, C.** Memory Game and special HCI device in stroke therapy, K. Miesenberger et al. (Eds.): ICCHP 2016, Part I, *LNCS 9758*, pp: 545-548, Springer International Publishing Switzerland, 2016, DOI: 10.1007/978-3-319-41264-1_74

[48] Kordigel Aberšek, M., Aberšek, B., Dolenc, K., **Sik-Lanyi, C.**, Shirmohammadi, S., Van Isacker, K., Grudeva, P., Szucs, V., Guzsvinecz, T. Intelligent Serious Games for Learning in Informal Learning Environment, 2nd International Scientific Conference on Philosophy of Mind and Cognitive Modelling in Education, Maribor, Slovenia May 7-8, 2018.

[49] Cerbas, S., Kelemen, A, Liang,Y., Czank,A., **Sik-Lanyi**, C., Scala,E., Van De Castle, B. Development and Usability Testing of a Physical Activity Mobile App for Hematopoietic Stem Cell Transplant Patients, 28th Summer Institute in Nursing

Informatics Conference (SINI2018), poster, July 18-20, 2018, Baltimore, USA (This poster has got People's Choice Award)

[50] Proszenyak, G.L., Arvai, A**., Sik-Lanyi, C.**, Czank, A., Kelemen, A., Cerbas, E., van De Castle B., Lian, Y., Simon, Cs., Revesz, F. Walking Warrior. In: Vassanyi I. (Ed.) Proceedings of the Pannonian Conference on Advances in Information Technology (PCIT'2019) pp. 113-118. Veszprem, Hungary, University of Pannonia, May 31 – June 1, 2019. ISBN 978-963-396-127-8

[51] Bodor, B., Szabó, P., **Sik-Lanyi, C.** Re-Creation, and android game. In: Vassanyi I. (Ed.) Proceedings of the Pannonian Conference on Advances in Information Technology (PCIT'2019) pp. 119-125. Veszprem, Hungary, University of Pannonia, May 31 – June 1, 2019. ISBN 978-963-396-127-8

[52] **Sik-Lanyi, C.**, Szabo, P., Bodor, B. Developing an Android Game for Restoring the Motor Functions of Fingers, 15th AAATE Conference: GLOBAL CHALLENGES IN ASSISTIVE TECHNOLOGY, Bologna (IT), 27-30 August 2019

[53] **Sik-Lanyi, C.**, Kelemen, A., Revesz, F., Simon, Cs., Cerbas, S., van De Castle, B., Proszenyak, G., Arvai, A., Liang, Y. Mobile Health Game Development to Motivate Walking for Hematopoietic Stem Cell Transplant Patients, 15th AAATE Conference: Global Challenges in Assistive Technology, Bologna (IT), 27-30 August 2019

[54] **Sik-Lanyi, C.** Accessibility testing of local government websites in Hungary, XXXII. Neumann Kollokvium, pp. 52-57. Veszprém, Hungary, 25-26 October 2019. ISBN: 978-615-5036-16-3

The author's other connected publications

[55] **Sik Lányi, C.** Multimedia Software Interface Design for Special Needs Users. *Encyclopedia of Information Science and Technology,* 2nd Edition, IGI Global, 2008, DOI: 10.4018/978-1-60566-026-4.ch440, ISBN13: 9781605660264, ISBN10: 1605660264, EISBN13: 9781605660271, pp. 2761-2766.

[56] **Sik Lányi, C.** Lights and colours in virtual reality. *Colour Coded* by Parraman C. (Eds.) Published by The Society of Dyers and Colourists, Brabdford, 2010, ISBN 978-0-901956-86-6, pp. 152-163.

[57] **Sik Lányi, C**. Choosing effective colours for websites. *Colour design Theories and application* by Best J. (Ed) Published by Woodhead Publishing Limited, 2012, ISBN 978-1-84569-972-7, pp.600-621.

[58] **Sik Lányi, C.** Choosing effective colours for websites, *Colour design, Theories and application*, by Best J. (Ed) 2nd. Edition, Published by Elsevier, Woodhead Publishing, 2017, ISBN 978-0-08-101270-3 (in print), ISBN 978-0-08-101889-7 (in print), pp.619-640.

[59] **Sik Lányi, C.** Cultural background influence on colours of virtual reality games and apps, *Colour design, Theories and application*, by Best J. (Ed) 2nd. Edition, Published by Elsevier, Woodhead Publishing, 2017, ISBN 978-0-08-101270-3 (in print), ISBN 978-0-08-101889-7 (in print), pp.529-555.

[60] **Sik Lányi, C.** Accessibility Testing of Social Websites. *Handbook of Social Network Technologies and Applications* by Furth B. (Ed) Springer Science + Business Media, LLC 2010, ISBN: 978-1-4419-7141-8, pp. 409-426.

[61] **Sik Lanyi, C.**, Szucs, V. Motivating Rehabilitation Through Competitive Gaming. *Modern Stroke Rehabilitation through e-Health-based Entertainment* by E. Vogiatzaki, A. Krukowski (Eds.). Springer-Verlag, 2016, pp. 137-167, ISBN 978-3-319-21292-0 (printed), ISBN 978-3-319-21293-7 (eBook), DOI: 10.1007/978-3-319-21293-7

[62] **Sik Lányi, C.**, Laky, V., Tilinger, Á., Pataky, I., Simon, L., Kiss, B., Simon, V., Szabó, J., Páll, A. Developing Multimedia Software and Virtual Reality Worlds and their Use in Rehabilitation and Psychology. *Transformation of Healthcare with Information Technologies*. IOS Press, 2004, pp. 273-284. ISBN 1-58603-438-3, ISSN 0926-9630

[63] **Sik Lányi, C.**, Simon, V., Pataky, I., Kosztyán Zs. T, Mátrai, R. Medical Applications of Virtual Reality Worlds and Multimedia. *Overcoming the barries to e-health growth in Enlarged Europe,* Health and Management Press, Krakow, 2004**,** pp. 189-204. ISBN 83-916649-4-5

[64] **Sik Lányi, C.** Multimedia Medical Informatics System in Healthcare. *Intelligent Paradigms for Assistive and Preventive Healthcare*, Ichalkaranje, A., et al. (Eds.), Springer-Verlag, 2006, pp. 39-91. ISBN 3-540-31762-7

[65] **Sik Lányi, C.** Virtual Reality in Healthcare. *Intelligent Paradigms for Assistive and Preventive Healthcare,* Ichalkaranje, A., et al. (Eds.), Springer-Verlag, 2006, pp. 92-121. ISBN 3-540-31762-7

[66] **Sik Lányi, C**. Multimedia Software Interface Design for Special Needs Users, *Encyclopedia of Information Science and Technology*. 2nd Edition, IGI Global, 2008, DOI: 10.4018/978-1-60566-026-4.ch440, ISBN13: 9781605660264, ISBN10: 1605660264, EISBN13: 9781605660271, pp. 2761-2766

[67] **Sik-Lanyi, C.**, Szucs, V. Play for children with disabilities: some reflections on the results on the users' needs and on the role of technologies, *Users' Needs Report on Play for Children with Disabilities - Parents' and children's views*, by M. Allodi Westling, T. Zappaterra (Eds.) De Gruyter Poland Ltd, Warsaw/Berlin, 2017, ISBN: 978-3-11-053745-1, e-ISBN: 978-3-11-053748-2, Chapter 10, pp. 117-123.

[68] *The Thousand Faces of Virtual Reality*, Edited by **Cecilia Sik Lanyi**, ISBN 978-953-51-1733-9, Hard cover, 170 pages, Publisher: InTech, Published: 26 November, 2014 under CC BY 3.0 license, in subject Human-Computer Interaction DOI: 10.5772/58637 http://www.intechopen.com/books/the-thousand-faces-of-virtual-reality

[69] **Sikné Lányi, Cecília**, Mógánné Tölgyesy, Szilvia, Szücs, Veronika Virtuális valóság alapú játék fejlesztése az Országos Orvosi Rehabilitációs Intézet ergoterápis részlege páciensei rehabilitációjának elősegítésére, *Rehabilitáció*, 2019, 29(1):3-10.

[70] EDeAN Publication 2009 – Principles and Practice in Europe for e-Accessiblity, 2009, **C. Sik Lányi** (ed.), Pannonian University Press, ISBN 978 963 9696 76 1

Publications connected to the theses

[71] Disability Statisctics: http://www.disabled-world.com/disability/statistics/

[72] Bowman, D.A., Kruijff, E., Laviola Jr., J.J., Poupyrev, I. 3D User Interfaces. Addison-Wesley, 2004.

[73] Stahre, B. How to Convert Reality into Virtual Reality: Exploring Colour Appearance in Digital Models. Thesis for degree of licentiate of engineering, Chalmers University of Technology, Götenborg, Sweden. (2006)

[74] Stahre, B. Defining Reality in Virtual Reality: Exploring Visual Appearance and Saptial Experience Focusing on Color. Thesis for the degree of Doctor of Philosophy, Chalmers University of Technology, Götenborg, Sweden. (2006)

[75] Steinkuehler, C. Massively Multiplayer Online Games – Based Learning, M3 – Interdisciplinary Aspects on Digital Media & Education, Workshop, Wien, Austria, Nov. 23, 2006, pp. 15-16.

[76] Bodrogi, P., Tarczali, T. Colour memory for various sky, skin and plant colours: effect of the image context, *Color Res. Appl.* 26, 278-289. (2001)

[77] Tarczali, T., Park, D.S., Bodrogi, P., Kim C.Y. Long-term memory colours of Korean and Hungarian observers. *Color Res. Appl.* 31:176-183. (2006)

[78] Komlodi, A., Hercegfi, K. Exploring Cultural Differences in Information Behavior Applying Psychophysiological Methods. *CHI2010 (ACM Conference on Human Factors in Computing Systems)*, April 10-15, 2010, Atlanta, GA, USA, Proceedings pp. 4153-4158, ACM Press, ISBN:978-1-60558-930-5: http://portal.acm.org/citation.cfm?doid=1753846.1754118

[79] Clemmensen, T., Hertzum, M., Hornbaek, K., Qingxin, S., Yammiyavar, P. Cultural cognition in usability evaluation. *Interacting with Computers*. 21: 212-220. (2009)

[80] Hall, E.T. The Hidden Dimension. Doubleday, New York, NY, USA. (1990)

[81] Gao, X.P., Xin, J.H., Sato, T., Hansuebsai, A., Scalzo, M., Kaiwara, K., Guan, S.S., Valldeperas, J., Lis, M.J., Billger, M. Analysis of Cross-Cultural Color Emotion. *Color Research & Application*. **32**(3):223-229. (2007)

[82] Hupka, R.B., Zaleski, Z., Otto, J., Reidl, L. Tarabrina, N.V. BThe colors of anger, envy, fear, and jealousy: A crosscultural study,[J. Cross Cult. Psychol., vol. 28, no. 2, pp. 156–171, Mar. 1997.

[83] Ou, L.C., Luo, M.R., Sun, P.L., Hu, N.C., Chen, H.S., Guan, .S., Woodcock, A., Caivano, J.L., Huertas, R., Tremeau, A., Billger, M., Izadan, H., Richter, K.,BA cross-cultural comparison of colour emotion for two-colour combinations, *Color Res. Appl.*, vol. **37**(1), pp. 23–43, Feb. 2012.

[84] Sato, T., Kajiwara, K., Hoshino, H., Nakamura, T. Quantitive evaluation and categorization of human emotion induced by colour. *Adv. Colour Sci Technol.* **3**:53-59. (2000)

[85] 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. *OPTICS EXPRESS* (ISSN: 1094-4087) **22**:(26):32308-32328. (2014)

[86] Westland, S., Laycock, K., Cheung, V., Henry, P., Mahyar, F. Colour harmony. *Colour: Desing & Creativity*. **1**(1):1–15. (2007) http://www.colour-journal.org/2007/1/1/07101article.htm#refs

[87] Statistics and How many people are Color blind: https://iristech.co/statistics/

[88] Colour Blind Awareness: http://www.colourblindawareness.org/colour-blindness/

[89] Universal Design http://www.universaldesign.com/

[90] Accessibility for the Disabled, A Design Manual for a Barrier Free Environment: http://www.un.org/esa/socdev/enable/designm/

[91] European Commission, 2014: Priority, Digital Single Market, Bringing down barriers to unlock online opportunities, http://ec.europa.eu/priorities/digital-single-market_en

[92] European Commision, Press release, 2015: *Commission proposes modern digital contract rules to simplify and promote access to digital content and online sales across the EU,* http://europa.eu/rapid/press-release_IP-15-6264_en.htm

[93] European Commision, Press release, 2016: Commission proposes new e-commerce rules to help consumers and companies reap full benefit of Single Market http://europa.eu/rapid/press-release_IP-16-1887_en.htm

[94] Online Kiskereskedelmi Index-1: http://www.gkidigital.hu/2016/05/26/22-millioszor-vasaroltunk-tavaly-az-interneten /

[95] Online Kiskereskedelmi Index-2: http://www.gkidigital.hu/oki/

[96] GKI Digital: https://gkidigital.hu/2019/03/12/425-milliard-forint-forgalom-2018/

[97] E-kereskedelem statisztikák: https://minner.hu/e-kereskedelem-statisztikak-2019/

[98] Foreign online shopping habits: https://gkidigital.hu/2019/11/21/kulfoldi-online-vasarlas/

[99] Világgazdaság: https://www.vg.hu/vallalatok/kereskedelem/16-szazalekkal-nott-a-hazai-online-kiskereskedelmi-forgalom-2102907/

[100] The winner of the coronavirus ?! - e-commerce is gaining momentum: https://gkidigital.hu/2020/03/11/brutto-625-milliard-forintert-vasaroltunk-tavaly-a-hazai-webaruhazakbol/

[101] WHO news room: https://www.who.int/news-room/detail/27-04-2020-who-timeline---covid-19

[102] EC.EUROPA.EC-news: https://ec.europa.eu/jrc/en/news/coronavirus-pandemic-reveals-large-differences-prevalence-telework-across-eu

[103] EC.EUROPA.EC-policy brief: https://ec.europa.eu/jrc/sites/jrcsh/files/jrc120945_policy_brief_-_covid_and_telework_final.pdf

[104] European Commission (2003) 2010: A Europe Accessible for All, Brussels: http://www.accessibletourism.org/resources/final_report_ega_en.pdf

[105] European Commission (2007): Ageing Well in the Information Society, COM (2007)332 final, Brussels: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2007:0332:FIN:EN:PDF

[106] Karner, C., Horváth, O. A stroke megbetegedés gazdasági és társadalmi jelentősége IME - Az egészségügyi vezetők szaklapja. **13**(1): 47-50. (2014)

[107] Healthcare and care through distance spanning solutions, 24 practical examples from Nordic region, Nordic Welfare Centre, Hadnagy J. (ed), 2019, ISBN: 978-91-88213-52-5: https://nordicwelfare.org/wp-content/uploads/2020/01/NWC-VOPD-EN-webb.pdf

[108] WCAG 1.0: https://www.w3.org/TR/WAI-WEBCONTENT/#priorities

[109] WCAG 2.0: https://www.w3.org/TR/WCAG20/

[110] GlobeNewswrie: https://www.globenewswire.com/news-release/2020/05/29/2041108/0/en/Global-Augmented-Reality-and-Virtual-Reality-Market-is-expected-to-reach-USD-161-1-billion-by-2025-witnessing-48-8-CAGR-during-the-forecast-period-2020-2025-VynZ-Research.html

[111] VynZ Research: https://www.vynzresearch.com/ict-media/augmented-reality-and-virtual-reality-market/request-sample

[112] Schanda, J. (ed): Colorimetry: Understanding the CIE System, Wiley-Interscience, 2007, ISBN: 978-0-470-04904-4

[113]: ISO/CIE 11664-4:2019(E) Colorimetry — Part 4: CIE 1976 L*a*b* colour space

[114] Bartleson, C.J. Memory colors of familiar objects. *J. OSA,* **50:** 73-77. (1960)

[115] Tarczali, T. Investigation of color memory, PhD thesis, University of Pannonia, (2007)

[116] StrokeBack project: Telemedicine System Empowering Stroke Patients to Fight Back, Grant Agreement Number: 288692, http://www.strokeback.eu/

[117] ETRE colour-blindness simulator: http://www.etre.com/tools/colourblindsimulator/

[118] Coblis by colblindor: http://www.color-blindness.com/coblis-color-blindness-simulator/

[119] ASP.NET ASP.NET colour-blindness simulator: http://aspnetresources.com/tools/colorBlindness

[120] ColorOracle: http://colororacle.org/

[121] AChecker: https://achecker.ca/checker/index.php

[122] Google Chrome SEE app.: https://chrome.google.com/webstore/detail/see/dkihcccbkkakkbpikjmpnbamkgbjfdcn

[123] Variantor – an experience based tool to aid universal design: http://variantor.com

[124] WebXACT: http://www.w3c.hu/talks/2006/wai_de/mate/watchfire.html

[125] XValid: own tdeveloped est software

[126] Nibbler: https://nibbler.silktide.com/

[127] Goodwin, M., Susar, D., Nietzio, A., Snaprud, M., Jensen, C.S. Global Web Accessibility Analysis of National Government Portals and Ministry Web Sites, *Journal of Information Technology & Politics*, **8**, 41-67 (2011)

[128] GOET project: GAME ON EXTRA TIME - Serious Educational Games to develop Prevocational Skills in People with Learning Difficulties, projekt azonosító: UK/08/LLP-LdV/TOI/163-181

[129] ISG4Competence project: Intelligent Serious Games for Social and Cognitive Competence, projekt azonosító: 2015-1-TR01-KA201-022247

[130] CREATE project: "Colour Research for European Advanced Technology Employment" (MSCF-CT-2006-045963)

[131] DfA "Design for All for eInclusion" DfA@eInclusion 033838 project

[132] WebAccess project: web_access "Joint Programme on Accessible Web Design" (133818-LLP-1-2007-1-AT-ERASMUS-ECDEM)

[133] LUDI TD COST Action TD1309 Play for Children With Disabilities: https://www.ludi-network.eu/

[134] COST CA19104 Advancing Social inclusion through Technology and Empowerment: https://www.cost.eu/cost-action/advancing-social-inclusion-through-technology-and-empowerment/#tabs|Name:overview

[135] Association for the Advancement of Assistive Technology in Europe (AAATE): https://aaate.net/

[136] King Salman Center For Disbaility Research: https://www.kscdr.org.sa/en/

[137] eNet Internet Research and Consulting Ltd., Home to 3.7 million gamers: https://enet.hu/news/hungary-home-to-3-7-million-gamers/?lang=en

[138] Deutsche Welle News, Jun 17, 2019:

https://www.dw.com/en/world-population-to-reach-97-billion-by-2050-un/a-49241728

[139] United Nations: WorlD Population Ageing 2019:

https://www.un.org/en/development/desa/population/publications/pdf/ageing/WorldPopulationAgeing2019-Highlights.pdf

[140] Nielsen, J. (2012): Introducing boomers: Marketing's most valuable generation:

https://www.nielsen.com/us/en/insights/report/2012/introducing-boomers--marketing-s-most-valuable-generation/

[141] Tath, W. (2020): How to successfully cater to older players:

https://www.gamesindustry.biz/articles/2020-07-06-how-to-successfully-cater-to-older-players

[142] Craig, A.B.; William, R.S.; Jeffrey, D.W. *Developing Virtual Reality Applications: Foundations of Effective Design*, Morgan Kaufmann Publishers, Burlington, 2009

[143] Girvan, C. *What is a virtual world?* Definition and classification, Education Tech Research Dev (2018) 66:1087–1100, https://doi.org/10.1007/s11423-018-9577-y

[144] Gabbard, J.L. A Taxonomy of Usability Characteristics in Virtual Environments. Thesis at the Department of Computer Science Virginia Polytechnic Institute and State University Blacksburg, VA 24061

[145] State, J. VR, AR or MR… What's the Difference & Why Should I Care:*, Applied Art & Technoogy* (May 1, 2017): http://www.appliedart.com/blog/vr-ar-or-mr-what-s-the-difference-why-should-i-care

[146] Interaction Design Foundation, Human-Computer Interactin (HCI): https://www.interaction-design.org/literature/topics/human-computer-interaction

[147] Hefley, W., Lynch, E., Buie, E., Muller, M., Hoecker, D., Carter, J., Roth, J. T. (1994). "Integrating Human Factors with Software Engineering Practices". In Proceedings of the Human Factors and Ergonomics Society 38th Annual Meeting, 1994, pp. 315-319. Republished in G. Perlman, G. K. Green, & M. S. Wogalter (Eds.) *Human Factors Perspectives on Human-Computer Interaction: Selections from Proceedings of Human Factors and Ergonomics Society Annual Meetings*, 1983-1994. Santa Monica, CA: HFES,

[148] Kapor, M. (1996). A software design manifesto. In Winograd, T., (ed.), *Bringing design to software*. Reading, MA: Addison-Wesley. Originally presented to Esther Dyson's PC Forum in 1990.

[149] Buie, E., A., & Vallone, A. (1997). Integrating HCI engineering with software engineering: A call to a larger vision. In Smith, M. J., Salvendy, G., & Koubek, R. J. (Eds.), *Design of Computing Systems: Social and Ergonomic Considerations* (Proceedings of the Seventh International Conference on Human-Computer Interaction), Volume 2. Amsterdam, the Netherlands: Elsevier Science Publishers, 1997, pp. 525-530. http://luminanze.com/writings/larger_vision.html

[150] Arriaga, P., Esteves, F., Fernandes, S. Playing for Better or for Worse?: Health and Social Outcomes with Electronic Gaming. In: *Handbook of Research on ICTs for Human-Centered Healthcare and Social Care Services*. IGI Global Publisher, 2013, pp. 48-69. DOI: 10.4018/978-1-4666-3986-7.ch003

[151] Gallegos, B., Kepple, M.T., Bukaty, C.A. Using Video Gameplay to Measure Achievement for Studetns with Disabilities: A New Perspective to Grading and Achievement Reporting. In: *Handbook of Research on Gaming Trends in P-12 Education*. IGI Global Publisher, 2016. pp. 326-352. DOI: 10.4018/978-1-4666-9629-7.ch016

[152] Neto, J., Mendes, P. Game Manager: More Than Virtual Managers. In *Handbook of Research on Serious Games as Educational*, Business and Research Tools. IGI Global Publisher, 2012. pp. 108-134. DOI: 10.4018/978-1-4666-0149-9.ch006

[153] Taylor, L.N. Gaming Ethics, Rules, Etiquette, and Learning. In: *Handbook of Research on Effective Electronic Gaming in Education*. IGI Global Publisher, 2009. pp. 1057-1067. DOI: 10.4018/978-1-59904-808-6.ch061

[154] Pavlidis, G.P., Markantonatou, S. Playful Education and Innovative Gamified Learning Approaches. In: *Handbook of Research on Educational Design and Cloud Computing in Modern Classroom Settings*. IGI Global Publisher, 2008. pp. 321-341. DOI: 10.4018/978-1-5225-3053-4.ch015

[155] Fromme, J., Jörissen, B., Unger, A. (Self-) Educational Effects of Computer Gaming Cultures. In: *Handbook of Research on Effective Electronic Gaming Education*. IGI Global Publisher, 2009. pp. 757-775. DOI: 10.4018/978-1-59904-808-6.ch043

[156] Natural Color System - The International Language of Color Communication, Website found at: http://www.ncscolor.com/

[157] MacDonald, L. *Color in Computer Graphics*, Lecture Notes, 2nd edition, MacColor Ltd. (1998)

[158] CIE Draft standard: Colorimetry – Part 4, (2006), CIE 1976 *L*a*b** color space, CIE DS 014-4.1.

[159] Witzel, R. F., Burnham, R. W. Onley, J. W. Threshold and suprathreshold perceptual color differences, *J. Opt. Soc. Am*. **63**, 615-625 (1973)

[160] Color difference. CIE. http://www.cie.co.at/publications/colorimetry-part-6ciede2000-colour-

[161] CIE TC 1-33 Color Rendering. Specifying Color Rendering Properties of Light Sources, 1996

[162] Itten, J. The Art of Color. Translation by Ernst van Haagen from German "*Kunst der Farbe*". New York: Van Nostrand Reinhold, 1961.

[163] Munsell, R.V.N. *A grammar of colour*, New York: Reinhold, 1969.

[164] Ostwald, W. *The color primer*. New York: Van Nostrand Reinhold, 1969.

[165] Goethe, J.W. *Theory of colours*, Cambridge, MA: MIT Press, 1970.

[166] Nemcsics, A. *Farbenlehre und Farbendynamik*, Budapest: Akadémiai Kiadó, 1993.

[167] Chevreul, M.E. *The principles of harmony and contrast of colours*, New York: Van Nostrand Reinhold, 1981.

[168] Judd, D.B. Wyszecki, G. *Colour in business, science and industry*, 3rd ed. New York: John Wiley, 1975.

[169] Accessibility for the Disabled, A Design Manual for a Barrier Free Environment: http://www.un.org/esa/socdev/enable/designm/ accessed 17 November 2018

[170] Government of Canada: https://www.canada.ca/en/treasury-board-secretariat/topics/government-communications.html accessed 17 November 2018

[171] WAIC.JP (in Japanese): Web Accessibility Infrastructure Commission. https://waic.jp/guideline/jis-x-8341-3_2010/ accessed 27 August 2018

[172] Stephen, T. Springer, SSB BART Group. http://www.ssbbartgroup.com/reference/laws-and-standards/section-508-of-the-rehabilitation-act/ (2010) accessed 21 August 2018

[173] WebAIM (Web Accessibility in Mind). World Laws Introduction to Laws Throughout the World. https://webaim.org/articles/laws/world/ accessed 27 August 2018

[174] Digital Accessibility Laws Around the Globe. Law Office of Lainey Feingold. https://www.lflegal.com/2013/05/gaad-legal/ (2013) accessed 27 August 2018

[175] Nakata, K. Deadlines Loom for Canada's Web Accessibility Law. HiSoft. http://blog.hisoftware.com/2013/accessibility/deadlines-loom-for-canadas-web-accessibility-laws (2013) accessed 27 August 2018

[176] ADA.gow: https://www.ada.gov/archive/t3hilght.htm accessed 27 August 2018

[177] Americans with Disabilities Act Title III Regulations. Nondiscrimination on the Basis of Disability in Public Accommodations and Commercial Facilities. https://www.ada.gov/regs2010/titleIII_2010/titleIII_2010_regulations.htm accessed 27 August 2018

[178] News European Parliament. MEPs vote to make online public services accessible to everyone. 26 February 2014. http://www.europarl.europa.eu/news/en/press-room/20140220IPR36573/meps-vote-to-make-online-public-services-accessible-to-everyone accessed 17 November 2018

[179] EUR-Lex. Directive (EU) 201662012 of the European Parliament and of the Council of 26 October 2016 on the accessibility of the websites and mobile applications of public sector bodies. published in the 'Official Journal of the European Union' on 2.12.2016. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32016L2102 accessed 17 November 2018

[180] WCAG 2.1: https://www.w3.org/TR/WCAG21/ accessed 15 March 2019

[181] What's new in WCAG 2.1: https://www.w3.org/WAI/standards-guidelines/wcag/new-in-21/ accessed 15 March 2019

[182] Itten, V. *Kunst und Farbe*, Otto Maier Verl. Ravensburg, 1970

[183] Panton, V. "*Choosing colours should not be a gamble. It should be a conscious decision. Colours have meaning and function*" as a title of his booklet, Danish Design Centre 1997.

[184] Hutchings, J.B. Color in anthropology and folklore, in *Color for science, art and technology*, ed. by: K Nassau, Elsevier, Amsterdam, 1998

[185] Robertson, D., Davies, I., Davidoff, J. Color categories are not universal: replications and new evidence from stone-age culture. *J. of Exp. Psychology*: 2000, General **129.** 369-98.

[186] Berlin, B., Kay, P. *Basic Color Terms. Their Universality and Evolution*, Berkeley: University of California Press, Reprinted 1991.

[187] Heider, E.R., Oliver D.C. The structure of the colour space in naming and memory for two languages, *Cogn. Psychol.*, 1972; **3**:337-354.

[188] Davidoff, J., Davies I., Roberson D. Colour categories in a store-age tribe. *Nature*, 1999; **398**:203-204.

[189] Brown, R.W., Lenneberg E.H. A study in language and congnition, *J Abnorm Psychol.* 1954;**49**:454-462.

[190] Thierry, G., Athanasopoulos P. Wiggett A., Dering B., Kuipers J-R., Unconscious effects of language-specific terminology on preattentive color perception, *Proc Natl Acad Sci USA,* 2009;**106**(11): 4567-4570

[191] Winawer, J. et al. Russian blues reveal effects of language on color discrimination. *Proc Natl Acad Sci USA*, 2007; **104**:7780-7785.

[192] Gilbert, A.L. Regier, T., Kay, P., Ivry, R.B. Whorf hypothesis is supported in the right visual field but not the left. *Proc Natl Acad Sci USA.* 2006; **103**:489-494.

[193] Drivonikou, G.V., et al. Further evidence that Whorfian effects are stronger in the right visual field than the left. *Proc Natl Acad Sci USA.* 2007;**104**:1097-1102.

[194] Duncan, J., Nobs, H.J."Coloring our emotions: the measurement and application of our responses to color", Abstract. PICS 04 Conference Glasgow, 2004.

[195] Szabó, F., Bodrogi, P., Schanda J. Experimental Modelling of Colour Harmony, *Color Research and Application*, 2010, **35**(1): 34-49, 10.1002/col.20558, ISSN: 0361-2317, Online ISSN: 1520-6378

[196] Szabó, F, Bodrogi, P., Schanda J. A Colour Harmony Rendering Index based on new Colour Harmony Formulae, *Lighting Research and Technology* 2009 **41**: 165-182, Online ISSN: 1477-0938 Print ISSN: 1477-1535

[197] Brown, D.J., Neale, H., Cobb, S.V. Reynolds, H. The development and evaluation of the virtual city. *International Journal of Virtual Reality*. (1999), **4**(1):.28-41.

[198] Standen, P.J., Brown, D.J. Virtual reality in the rehabilitation of people with intellectual disabilities: Review *Cyberpsychology and Behaviour,* (2005) 8, 3, pp. 272 - 282.

[199] Brown, D.J., Shopland, S., Battersby, S., Tully, A., Richardson, S. (2009) Game On: Accessible serious games for offenders and those at risk of offending. *Journal of*

Assistive Technologies, (2009) **3**(2):15-30**.** © Pavilion Journals (Brighton) Ltd.

[200] Komlódi, A., Józsa, E., Hercegfi, K., Kucsora, Sz., Borics, D. Empirical Usability Evaluation of the Wii Controller as an Input Device for the VirCA Immersive Virtual Space. *CogInfoCom* 2011, Budapest, Hungary, 2011 July 7-9., Proc. pp.1-6. ISBN 978-1-4577-1806-9.

[201] Komlódi, A., Hercegfi, K., Józsa, E., Köles, M. Human-information interaction in 3d immersive virtual environments. CogInfoCom 2012 - 3rd *IEEE International Conference on Cognitive Infocommunications*, Kosice, Slovakia, 2012 Dec 2-5. Proc. pp.597-600.

[202] Barfield, W., Hendrix, C., Bjorneseth, O., Kaczmarek, K.A., Lotens, W. Comparison of human sensory capabilities with technical specifications of virtual environment equipments, *Presense: Teleoperators and Virtual Environments*, **4**, 329-356.

[203] Witmer, B.G., Bailey, J.H., Knerr, B.W. 1996, Virtual spaces and real world places: transfer of route knowledge, *International Journal of Human-Computer Studies*, **45**, 413-428.

[204] Wilson, J.R. Virtual environments and ergonomics: needs and opportunities, *Ergonomics*, 1997, **40**(10): 1057-1077

[205] Denby, C.: Importance of Memory Color (2002), http://hubel.sfasu.edu/courseinfo/SL02/memory_color.htm

[206] Dyslexia home page: http://www.dyslexia-test.com/color.html

[207] Stanney, K.M. Handbook of virtual environments, ed. by: Stanney, K.M. editor, Handbook of Virtual Environments: *Design, Implementation and Applications*. Mahwah, N.J.: Lawrence Erlbaum Associates, Inc. (2002)

[208] Lowenstein, D. Essential facts about the video and computer game industry (2002), http://www.idsa.com/pressroom.html

[209] Gameaddiction: http://www.mediafamily.org/facts/facts_gameaddiction.shtml

[210] Molmann, S. For online addicts, relationship float between real, virtual worlds (2008), http://edition.cnn.com/2008/BUSINESS/01/29/digital.addiction/index.html

[211]Smith & Jones (2006): http://www.smithandjones.nl/eng/index.html

[212] Health24: http://www.health24.com/mind/Memory_and_cognition/1284-1297,12667.asp

[213] Kovács, A. Developing test software for investigation of memory color, M.Sc. thesis work, University of Pannonia (2007)

[214] Colourlite Colour Test (see a shorter version of this test: http://www.colourvision.info/test_colour_vision_deficiency.htm).

[215] Lyons, P, Moretti, G., Wilson, M. (2000) Colour group selection for computer interfaces, in Rogowitz BE and Pappas TN (eds), *Human Vision and Electronic Imaging V*, Proc. SPIE 3959, San Jose CA, 302–313. **DOI:** 10.1117/12.387167

[216] Colour-blindness simulator. Accessed: 2017 March 01. URL: http://www.encyclopedia.com/topic/color_blindness.aspx

[217] Karagol-Ayan, B. Universal usability in practice, *Colour vision confusion,* 2001, available at: URL:http://www.otal.umd.edu/uupractice/color/

[218] W3C: https://www.w3.org/

[219] Jani, R., Schrepp, M. (2005) Are the Web Accessibility Guidelines applicable and sufficient for Web Applications? 8th European conference for the advancement of assistive technology in Europe: *Assistive technology from virtuality to reality* (AAATE 2005), IOS Press, 2005, pp. 499-503.

[220] Schreep, M., Jani, R. (2005) Efficient keyboard support in web-pages, 8th European conference for the advancement of assistive technology in Europe: *Assistive technology from virtuality to reality* (AAATE 2005), IOS Press, 2005, pp. 504-508.

[221] W3C Quality Assurance Tools: http://www.w3.org/QA/Tools/

[222] RDF Validator: http://www.w3.org/RDF/Validator/

[223] XML Schema Validator: http://www.w3.org/2001/03/webdata/xsv

[224] MUTAT: http://www.w3.org/QA/Tools/MUTAT/

[225] Total Validator http://www.totalvalidator.com/

[226] González, M., Rivera, C., Pintado, I., Vidau, A. (2006) Testing Web Navigation for All: An Agent-Based Approach, 10th International Conference on Helping People with Special Needs (ICCHP 2006), *LNCS* 4061, Springer, 2006, pp. 223-229.

[227] Rangin, H.B. (2006), University of Illinois Tools and Techniques for Functional Web Accessibility, 10th International Conference on Helping People with Special Needs (ICCHP 2006), *LNCS* 4061, Springer, 2006, pp. 230-233.

[228] Miesenberger, K., Pühretmair, F. (2005) Help.gv.at – Accessible e-Government in Austria, 8th European conference for the advancement of assistive technology in Europe: *Assistive technology from virtuality to reality* (AAATE 2005), IOS Press, 2005, pp. 489-493.

[229] OECD data. https://data.oecd.org/pinboard-editor/ accessed 27 August 2018

[230] GDP Growth Rate, Europe. https://tradingeconomics.com/country-list/gdp?continent=europe accessed 27 August 2018

[231] Population Europe. http://www.worldometers.info/population/europe/ accessed 27 August 2018

[232] Europe, country, Demograhics, Age structure: https://www.indexmundi.com/site_map.html accessed 15 March 2019

[233] The World Bank, GNI per capita,Atlas method (current US$) in 2017: https://data.worldbank.org/indicator/NY.GNP.PCAP.CD?view=map accessed 15 March 2019

[234] The World Bank, GNI per capita, PPP (current US$) in 2017: https://data.worldbank.org/indicator/NY.GNP.PCAP.PP.CD?view=map accessed 15 March 2019

[235] Kuzma, J.M. Accessibility design issues with UK e-government sites. Government Information Quarterly. 141-146. (2010) https://doi.org/10.1016/j.giq.2009.10.004 accessed 26 August 2018

[236] Yu, D.S., Parmanto, B. US state government websites demonstrate better in terms of accessibility compared to federal government and commercial websites. *Government Information Quarterly*. **28**, 484-490 (2011) https://doi.org/10.1016/j.giq.2011.04.001 accessed 26 August 2018

[237] Olalere, A., Lazar, J. Accessibility of U.S. federal government home pages: Section 508 compliance and site accessibility statements. *Government Information Quarterly*. **28**, 303-309 (2011) https://doi.org/10.1016/j.giq.2011.02.002 accessed 26 August 2018

[238] Youngblood, N.E. Revisiting Alabama state website accessibility. *Government Information Quarterly*. **31**, 476-487. (2014) https://doi.org/10.1016/j.giq.2014.02.007 accessed 26 August 2018

[239] Wentz, B., Lazar, J., Stein, M., Gbenro, E.H., Ramsey, A. Danger, danger! Evaluating the accessibility of Web-based emergency alert sign-ups in the north-eastern United States. *Government Information Quarterly*. **31**, 488-497 (2014) https://doi.org/10.1016/j.giq.2014.02.010 accessed 26 August 2018

[240] Zeng, X., Parmanto, B. Evaluation of web accessibility of consumer health information websites. *AMIA Annu Symp Proc*. 2003:743-747 (2003).

[241] Oliveira, A. D. A., Eler, M. M. Strategies and Challenges on the Accessibility and Interoperability of e-Government Web Portals: A Case Study on Brazilian Federal Universities, 2017 *IEEE 41st Annual Computer Software and Applications Conference* (COMPSAC), Turin, 737-742, DOI: 10.1109/COMPSAC.2017.222 (2017).

[242] Kaoun, F., Almourad, M.B. Accessibility as an integral factor in e-government web site evaluation: The case of Dubai e-government. *Information Technology & People*. **27**, 208-228 (2014)

[243] European Commission, Press release, 2015: Commission proposes modern digital contract rules to simplify and promote access to digital content and online sales across the EU, http://europa.eu/rapid/press-release_IP-15-6264_en.htm (2015) accessed 27 August 2018

[244] European Commission, Press release, 2016: Commission proposes new e-commerce rules to help consumers and companies reap full benefit of Single Market http://europa.eu/rapid/press-release_IP-16-1887_en.htm (2016) accessed 27 August 2018

[245] Brown, D.J., McHugh, D., Standen, P., Evett, L., Shopland, N., Battersby, S. (2010) Designing location-based learning experiences for people with intellectual disabilities and additional sensory impairments, *Computers & Education*, doi: DOI: 10.1016/j.compedu.2010.04.014

[246] Department of Health (2001). Valuing People: a new strategy for learning disability for the 21st century. London: HMSO.

[247] *LSC, 2006. Accessed on 11th December 2009 from* www.lsc.gov.uk/LSCGOVUK/

[248] Bandura, A. (1994). Self-efficacy. In V. S. Ramachaudran (Ed.), *Encyclopedia of human behavior* (Vol. 4, pp. 71-81). New York: Academic Press.

[249] Bandura, A. (1977). *Social Learning Theory*. New York: General Learning Press.

[250] Ormond, J.E. (1999). *Human learning* (3rd ed.). Upper Saddle River, NJ: Prentice-Hall.

[251] Desurvire, H., Wiberg, C. (2008) Evaluating User Experience and Other Lies in Evaluating Games. *CHI Conference*, 2008, Florence, Italy. http://www.behavioristics.com/downloads/approach-final-wschi08.pdf

[252] Dumas, J.S., Redish, J.C. (1999). A Practical Guide to Usability Testing, intellect^{TM}, Exeter, England

[253] Standen, P.J., Lannen, T.L., Brown, D.J. (2002), Control of virtual environments for people with intellectual disabilities. In Keates S, Langdon P, Clarkson PJ, Robinson P (eds) *Universal access and assistive technology*. pp.63 - 72. Springer-Verlag: London.

[254] Newell, A. F. Gregor, P. (2000). User Sensitive Inclusive Design – in search of a new paradigm. Proceedings of the *A.C.M. Conference on Universal Usability*, Washington DC. November 2000, pp.39-44.

[255] Daly-Jones, O., Bevan, N., Thomas, C. (1999). INUSE: *Handbook of User-Centred Design, Serco Usability Services*, National Physical Laboratory.

[256] Poulson, D.F., Waddell, F.N. (2001) USERfit: User centred design in assistive technology. In CA Nicholle &J Abascal (Eds) *Inclusive guidelines for HCI*. Tailor and Francis.

[257] Department of Health (2001). Valuing People: a new strategy for learning disability for the 21st century. London: HMSO.

[258] Tomlinson, J. (1997). Inclusive learning: the report of the committee of enquiry into the post-school education of those with learning difficulties and/or disabilities, in England 1996. *European Journal of Special Needs Education* **12**, 184-196.

[259] National Development Group for the Mentally Handicapped. (1977). Day Services for Mentally Handicapped Adults. London: Department of Health and Social Security.

[260] Hawkridge, D., & Vincent, T. (1992). *Learning Difficulties and Computers*. London: Jessica Kingsley.

[261] Blamires, M. (ed.), (1999). *Enabling Technology for Inclusion*. London: Paul Chapman Publishing.

[262] Elgi, E.A., Meyers, L.S. (1984). The role of video game playing in adolescent life; is there a reason to be concerned? *Bulletin of the psychonomic society*, **22**, 309-312.

[263] Pivec, M. (2007). Editorial: Play and learn: potentials of game-based learning. British *Journal of Educational Technology*, **38**(3), 387-393.

[264] Griffiths, M. (2004). Can videogames be good for your health? *Journal of Health Psychology*, **9**(3), 340-343.

[265] Standen, P.J., Karsandas, R.B., Anderton, N., Battersby, S., Brown, D.J. (2009). An evaluation of the use of a computer game in improving the choice reaction time of adults with intellectual disabilities. *Journal of Assistive Technologies*, **3**(4):4-11, (c) Pavilion Journals (Brighton) Ltd.

[266] Standen, P.J., Rees, F. Brown D.J. (2009). Effect of playing computer games on decision making in people with intellectual disabilities. *Journal of Assistive Technologies*, **3**(2):6-15. (c) Pavilion Journals (Brighton) Ltd.

[267] Garris, R., Ahlers, R., Driskell, J. E. (2002). Games, motivation and learning. Simulation & Gaming; An Interdisciplinary *Journal of Theory, Practice and Research*, **33**(4): 43–56.

[268] Hercegfi, K. (2011). Heart Rate Variability Monitoring during Human-Computer Interaction, *Acta Polytecnica Hungarica*; **8**(5): 205-224.

[269] Brown, D.J., Standen, P., Evett, L., Battersby, S., Shopland, N. Designing Serious Games for People with Dual Diagnosis: *Learning Disabilities and Sensory Impairments*. In Press in Educational Gaming. IGI Global, editors Pavel Zemliansky; Diane Wilcox.

[270] ISO 9241-11. (1998). Ergonomic requirements for office work with visual display terminals (VDT)s – Part 11 guidanceon usability.

[271] Benjamin, E.J., Blaha, M.J., Chiuve, S.E. et al. on behalf of the American Heart Association Statistics Committee and Stroke Statistics Subcommittee. Heart disease and stroke statistics—2017 update: a report from the American Heart Association. *Circulation*. 2017;135:e229-e445.

[272] The Burden of Stroke in Europe: https://www.stroke.org.uk/sites/default/files/the_burden_of_stroke_in_europe_-_challenges_for_policy_makers.pdf

[273] GBD 2016 Stroke Collaborators. Global, regional, and national burden of stroke, 1990-2016: a systematic analysis for the Global Burden of Disease Study 2016. *Lancet Neurol*. 2019;**18**(5):439-458. doi:10.1016/S1474-4422(19)30034-1

[274] Feigin, V. et al. Global, Regional, and Country-Specific Lifetime Risks of Stroke, 1990 and 2016. *New Engl J Med* 2018;379:2429-2437

[275] Kizony, R., Katz, N., Weingarden, H., Weiss P.L. (2002) Immersion without encumbrance: adapting a virtual reality system for the rehabilitation of individuals with stroke and spinal cord injury. Proc. *4th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, in Sharkey, Sik Lányi & Standen (Eds.) pp. 55-62, Veszprém, Hungary, 18-20 Sept. 2002.

[276] Kizony, R., Katz, N., Weiss P.L. (2004) Virtual reality based intervention in rehabilitation: relationship between motor and cognitive abilities and performance within virtual environments for patients with stroke. Proc. *5th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, in Sharkey, McRindle &Brown (Eds), pp. 19-26, Oxford, UK, 20-22 Sept. 2004.

[277] Broeren, J., Georgsson, M., Rydmark, M., Stibrant Sunnerhagen, K. (2002) Virtual reality in stroke rehabilitation with the assistance of haptics and telemedicine. Proc. *4th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, in Sharkey, Sik Lányi & Standen (Eds.) pp. 71-76, Veszprém, Hungary, 18-20 Sept. 2002.

[278] Connor, B.B., Wing, A.M., Humphreys, G.W., Bracewell, R.M., Harvey D.A. (2002) Errorless learning using haptic guidance: research in cognitive rehabilitation following stroke. Proc. *4th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, in Sharkey, Sik Lányi & Standen (Eds.) pp. 77-83, Veszprém, Hungary, 18-20 Sept. 2002.

[279] Davies, R.C., Löfgren, E., Wallergård, M., Lindén, A., Boschian, K., Minör, U. Sonesson, B., Johansson G. (2002) Three applications of virtual reality for brain injury rehabilitation of daily tasks. Proc. *4th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, in Sharkey, Sik Lányi & Standen (Eds.) pp. 93-100, Veszprém, Hungary, 18-20 Sept. 2002.

[280] Wallergård, M., Cepciansky, M., Lindén, A., Davies, R.C., Boschian, K., Minör, U., Sonesson, B., Johansson G. (2002) Developing virtual vending and automatic service machines for brain injury rehabilitation. Proc. *4th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, in Sharkey, Sik Lányi & Standen (Eds.) pp. 109-114, Veszprém, Hungary, 18-20 Sept. 2002.

[281] Pareto, L., Broeren, J., Goude, D., Rydmark, M. (2008) Virtual reality, haptics and post-stroke rehabilitation in practical therapy, Proc. *7th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, in Sharkey, Lopes dos Santos & Weiss (Eds.) pp. 245-252, Maia & Porto, Portugal, 8-11 Sept. 2008.

[282] Burke, J.W., McNeill, M.D.J., Charles, D.K., Morrow, P.J., Crosbie, J.H., McDonough S.M. (2010) Designing engaging, playable games for rehabilitation, Proc. *8th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, in Sharkey & Sánchez (Eds), pp. 195-201, Viña del Mar/Valparaíso, Chile, 31 Aug. - 2 Sept. 2010.

[283] Stephanidis, E. Universal access to ambient intelligence environments: Opportunities and challenges for people with disabilities. *IBM System Journal*, **44**(3):605-619 (2005).

[284] Holzinger, A., Ziefle, M., Röcker C. (2010) Human-Computer Interaction and Usability Engineering for Elderly. Proc. 12th Intl Conf. on Computers Helping People with Special Needs, in Mesenberger et al. (Eds) Part II, *LNCS* 6180. pp. 556-559, 2010.

[285] Jo, K., Yu, J., Jung, J. (2012) Effects of Virtual Reality-Based Rehabilitation on Upper Extremity Function and Visual Perception in Stroke Patients: a Randomized Control Trial. *Journal of Physical Therapy Science*, **24**(11):1205-1208

[286] WMFT Rehabilitation measures database, Rehab measures: Wolf Motor Function Test: http://www.rehabmeasures.org/Lists/RehabMeasures/DispForm.aspx?ID=927

[287] Standen, P.J., Brown, D.J., Battersby, S., Walker, M., Connell, L., Richardson, A. Platts F, Threapleton K, Burton A (2011) A study to evaluate a low cost virtual reality system for home based rehabilitation of the upper limb following stroke. International *Journal of Dis-ability and Human Development*. **10**(4):337-341 DOI: 10.1515/IJDHD.2011.063

[288] Standen, P.J., Threapleton, K., Connell, L., Richardson, A., Battersby, S., Brown, D.J., Platts, F., (2013) A low cost virtual reality system for home based rehabilitation of the upper limb following stroke: a randomized controlled feasibility trial. *International Journal of Stroke*. 8(Suppl.3):29.

[289] Structured System Analysis and Design Method. Available online: http://www.selectbs.com/analysis-and-design/what-is-ssadm

[290] Maradit Kremers, H., Larson, D.R., Crowson, C.S., Kremers, W.K., Washington, R.E., Steiner, C.A., Jiranek, W.A. Berry, D.J. Prevalence of total hip and knee replacement in the united states. *J. Bone Joint Surg. Am*. **2015**, *97*, 1386–1397, doi:10.2106/JBJS.N.01141.

[291] Cooke, M., Walker, R., Aitken, L.M., Freeman, A., Pavey, S., Cantrill, R. Pre-operative self-efficacy education vs. usual care for patients undergoing joint replacement surgery: A pilot randomised controlled trial. *Scand. J. Caring Sci*. **2016**, *30*, 74–82, doi:10.1111/scs.12223.

[292] Bailey, L. Strategies for decreasing patient anxiety in the perioperative setting. *AORN J.* **2010**, *92*, 445–457, doi:10.1016/j.aorn.2010.04.017.

[293] Ayyadhah Alanazi, A. Reducing anxiety in preoperative patients: A systematic review. *Br. J. Nurs*. **2014**, *23*, 387–393.

[294] Cohen, R.A., Adams, P.F. Use of the Internet for Health Information: United States, 2009. *NCHS Data Brief.* **2011**, 66, 1-8. Available online: https://www.ncbi.nlm.nih.gov/pubmed/22142942 (accessed on 29 January 2019).

[295] Johansson, K., Nuutila, L., Virtanen, H., Katajisto, J., Salanterä, S. Preoperative education for orthopaedic patients: Systematic review. *J. Adv. Nurs*. **2005**, *50*, 212.

[296] Hering, K., Harvan, J., Dangelo, M., Jasinski, D. The use of a computer website prior to scheduled surgery (a pilot study): Impact on patient information, acquisition, anxiety level, and overall satisfaction with anesthesia care. *AANA J.* **2005**, *73*, 29–33.

[297] Kruzik, N. Benefits of preoperative education for adult elective surgery patients. *AORN J.* **2009**, *90*, 385–387, doi:10.1016/j.aorn.2009.06.022.

[298] Nahm, E., Stevens Scott, P., Gorman, K. Effects of a web-based preoperative education program for patients who undergo ambulatory surgery. *J Hosp Adm*. **2012**, *1*, 21.

[299] Heikkinen, K., Leino-Kilpi, H., Salanterä, S. Ambulatory orthopaedic surgery patients' knowledge with internet-based education. *Methods Inf. Med*. **2012**, *51*, 295–300, doi:10.3414/ME11-02-0004.

[300] Keulers, B.J., Welters, C.F.M., Spauwen, P.H.M., Houpt, P. Can face-to-face patient education be replaced by computer-based patient education? A randomised trial. *Patient Educ. Couns*. **2007**, *67*, 176–182, doi:10.1016/j.pec.2007.03.012.

[301] Jeong, Y.W., Kim, J.A. Development of computer-tailored education program for patients with total hip replacement. *Healthc. Inform. Res*. **2014**, *20*, 258–265, doi:10.4258/hir.2014.20.4.258.

[302] Nahm, E., Preece, J., Resnick, B., Mills, M.E. Usability of health web sites for older adults: A preliminary study. *Comput. Inform. Nurs.* **2004**, *22*, 326–334.

[303] Nahm, E., Resnick, B., Mills, M.E. Development and pilot-testing of the perceived health web site usability questionnaire (PHWSUQ) for older adults. *Stud. Health Technol. Inform*. **2006**, *122*, 38–43.

[304] Heikkinen, K., Suomi, R., Jääskeläinen, M., Kaljonen, A., Leino-Kilpi, H., Salanterä, S. The creation and evaluation of an ambulatory orthopedic surgical patient education web site to support empowerment. *Comput. Inform. Nurs*. **2010**, *28*, 282–290, doi:10.1097/NCN.0b013e3181ec23e6.

[305] Ortiz, J., Wang, S., Elayda, M.A., Tolpin, D.A. Scientific article: Preoperative patient education: Can we improve satisfaction and reduce anxiety? *Braz. J. Anesthesiol.* **2015**, *65*, 7–13, doi:10.1016/j.bjane.2013.07.009.

[306] Beaudoin, D.E., Rocha, R.A., Tse, T. Enhancing access to patient education information: A pilot usability study. In *AMIA Annual Symposium Proceedings*; American Medical Informatics Association: Bethesda, MD, USA, 2005; p. 892.

[307] Sutton, M. Links vs. Bottons in Moders Web Applications. Marcysutton.com Web Site. Available online: https://marcysutton.com/links-vs-buttons-in-modern-web-applications/ (accessed on 8 July 2016).

[308] Conradsen, S., Gjerseth, M.M., Kvangarsnes, M. Patients' experiences from an education programme ahead of orthopaedic surgery—A qualitative study. *J. Clin. Nurs*. **2016**, *25*, 2798–2806, doi:10.1111/jocn.13281.

[309] Edward, G.M., Naald, N., Oort, F.J., de Haes, H.C.J.M., Biervliet, J.D., Hollmann, M.W., Preckel, B. Information gain in patients using a multimedia website with tailored information on anaesthesia. *BJA Br. J. Anaesth*. **2011**, *106*, 319.

[310] Bossen, D., Veenhof, C., Dekker, J., de Bakker, D. The usability and preliminary effectiveness of a web-based physical activity intervention in patients with knee and/or hip osteoarthritis. *BMC Med. Inform. Decis. Mak*. **2013**, *13*, 61, doi:10.1186/1472-6947-13-61.