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ANALYSIS OF THE USABILITY AND ACCESSIBILITY OF WEBSITES IN VIEW OF THEIR UNIVERSAL DESIGN PRINCIPLES

Abstract

Universal design is a strategic approach for planning and designing both the products and their environment, aimed at making a given product available to the widest number of possible users. It ensures equality for all of them and the opportunity to participate in the society. This concept is also crucial in the process of designing and developing software. The research was conducted with the use of four services, three of them were implemented for the purpose of this study. Two of them took into consideration the principles of universal design, while the others did not. The aim of the study was verification of the level of usability and accessibility of services by means of three independent methods: the LUT (Lublin University of Technology) checklist, an assessment taking into account WCAG 2.0 (Web Content Accessibility Guidelines) standards using the automatic WAVE evaluation tool (Web Accessibility Evaluation Tool) and a device allowing to track the movement of the eye while performing various tasks on websites. The websites were assessed by twenty experts in the field of creating web application interfaces, using the LUT checklist. The time to the first fixation (TTFF) that it took respondents to look at specific website elements was measured using the eye tracker device and iMotions software. All websites were checked by means of the WAVE tool to detect irregularities and non-compliance with universal design standards. The analysis performed clearly indicated that websites that follow the universal design guidelines were more useful, intuitive and accessible for users. It might be concluded that interfaces allow to find necessary information and perform desired actions in a shorter time when prepared in accordance with the principles of universal design.

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1. INTRODUCTION

Access to the Internet has become much more common nowadays – about 60% of the Earth's population has it (Digital Around the World, n.d.). News services are the main, and often the only source of news from the world, used by millions of people. Among the users, a significant percentage of them are people with disabilities, often with defects that prevent proper vision or hearing. This problem is marginalized and, as research shows, many websites do not take into account users with special needs, which excludes them from the social space (Leszczyńska, 2019). Therefore, in order to enable all users to have equal access to all available information, special solutions are implemented to make it easier for people to receive content published in the Internet. The main institution dedicated to spread awareness about web accessibility is the World Wide Web Consortium – W3C (W3C, 2022). This year it has come up with the Web Accessibility Initiative, or WAI (Initiative (WAI), W3C Web Accessibility, n.d.). In addition to educational activities, it is also involved in the creation of new guidelines, the development of evaluation tools and conducting research, the effect of which is to improve the accessibility of graphical user interfaces (GUIs). The field that deals with equality in access to products and the environment is universal design (UD). It assumes access for as many users as possible, who can use them independently (Centre for Excellence in Universal Design, n.d.). It should be noted, however, that facilitating access to content via the Internet for people with disabilities is only one of many aspects of universal design. Another, equally important, is to facilitate access to information for technically excluded people. The needs of these people require taking into consideration specific functionalities at the interface design level in order to comfortably use the Internet resources. One of the above-mentioned groups are people with visual impairment. Depending on the type of visual impairment, they require additional GUI functionalities, such as: the ability to magnify the text, listening to content, or entering it by voice. One of the key issues for the interface to be clear and easy to use is the way elements are arranged on the page. For their correct implementation, the WCAG guidelines (Web Content Accessibility Guidelines 2.1., n.d.) are used. It is a set of rules and recommendations aimed at guaranteeing solutions to the largest group of users.

The aim of this paper was to build two websites, taking into consideration the WCAG guidelines, and then compare them with real equivalents existing in the Internet that do not meet the accessibility requirements. The principles of universal design were implemented during the development of both websites. In the case of the implementation of the former, the emphasis was placed on the placement of GUI elements, while in the case of the latter – on the contrast settings. An experiment was prepared for the analysis, in which three different research methods were used. The eye tracking technique was used in the first analysis, the WAVE validator in the second, and the LUT (Lublin University of Technology) checklist in the last one. The impact of the placement of elements on the website on the speed of their location by the user, the number of errors according to the WCAG 2.0 standard and the ergonomics of the developed user interfaces were examined. As part of the work, two research hypotheses were formulated: "an information service limited by access barriers for people with visual impairment is less perceived and more difficult to use than an accessible service" and "a service made in accordance with the principles and guidelines of universal design is more intuitive to use".

2. LITERATURE REVIEW

Accessibility for people with various disabilities, broadly understood, has been a frequently analyzed scientific issue recently. In the article (Stasiak & Dzieńkowski, 2021) university websites were examined in terms of the level of their accessibility for people with disabilities. The study consisted of two parts. The first one uses a 13-question checklist, while the second one uses five automatic tools (Lighthouse, ACE, MAUVE ++, FAE, Utilitia) to evaluate websites in terms of their compliance with the WCAG standard. On the basis of the obtained results, the authors concluded that the analyzed websites required additional functionalities, such as the possibility of changing the interface colours and implementing the mobile version of the website.

The availability of library pages for people using screen readers was analyzed in (Yoon et al., 2016). Research was carried out, consisting of a survey part, in which participants reported accessibility problems, and a part in which automated testing tools were used. The results showed that the library sites are not accessible to users with visual impairments who use screen readers. The most frequently encountered accessibility barriers were due to problems with navigation and semantics, not to coding errors.

The article (Fogli, Provenza & Bernareggi, 2014) presents the developed language of design patterns ensuring accessibility also for blind designers, the creation of which was preceded by a three-stage analysis: heuristic evaluation, a survey and an analysis of created websites. The paper (Pascual et al., 2014) analyzed the impact of barriers on the mood of website users depending on the accessibility of information contained on websites. The study took into account time of performed tasks, efficiency as a way to understand the usefulness of the website through the percentage of positively completed tasks and the final satisfaction of each task. The results showed that the WCAG 2.0 compliant site had better performance, effectiveness and user satisfaction scores. The availability of the Norwegian Broadcasting Corporation's news services to ensure equal access to information for different social groups was analyzed in (Sanderson, Chen & Kessel, 2015). The study consisted of interviews with participants, analysis of functionality, structure and navigation of websites. Based on the answers provided and the heuristic assessment, it was concluded that the websites that participated in the study did not meet the standards compliant with WCAG 2.0. The availability of websites of universities, corporations and federal institutions in the USA, with particular emphasis on people with visual impairments, has been investigated in (Michalska et al., 2014). The results of more than ten years of research presented there proved that the analyzed websites were unavailable in terms of consistency and transparency according to the WCAG guidelines. The main cause of these problems was the constant change of information on pages, the rotation of people responsible for the appearance of the sites and too fast maintenance of the system, not taking into consideration the issues of compliance with WCAG rules. A similar study was presented in (Harper & Chen, 2012), where over 6,000 websites over 10 years were analyzed in terms of the accessibility standards used. The results showed that only 10% of the websites surveyed follow the WCAG guidelines.

The article (Pivetta et al., 2013) analyses a number of validation tools to verify the Moodle learning platform for compliance with WCAG 2.0 standards. The WAVE tool (WAVE Web Accessibility Evaluation Tool, n.d.) proved to be the most effective automatic validator. In some situations, an audit using one evaluation tool may turn out to be insufficient, as evidenced by the results of the study presented in (Kumar, Shree DV

& Biswa, 2021). The authors analyzed the availability of two news services using 10 of the most popular evaluation tools. This article (Acosta-Vargas, Acosta & Luján-Mora, 2018) analyzed 348 major Latin American university sites for WCAG 2.0 compliance errors using seven evaluation tools. The results showed that almost all of the analyzed websites were characterized by a significant number of errors, mainly concerning the contrast of elements on the page. The study (Ismail, Kuppusamy & Paiva, 2020) analyzed 59 websites of universities in Portugal in terms of the accessibility of websites for people with disabilities. The analysis was performed with the use of three tools for website validation according to the W3C standard: WAVE, AChecker and aXe. Based on the collected statistical data, it was found that the main problems of the pages concerned the contrasts of elements on the pages, links without visible text, alternative texts for graphics and buttons. It should be noted that the analysis with automatic evaluation tools may often turn out to be insufficient. The book (Abascal, Arrue & Valencia, 2019) compared solutions based on automated scripts and manual crowdsourcing solutions. The results showed that manual analysis was necessary to adapt the website for people with disabilities.

The graphical user interface design is one of the most important aspects when creating and implementing a website. The GUI must not only be readable, but also follow established conventions, such as the arrangement of individual elements on the page. Otherwise, it may be difficult to find the information one is interested in. A study (Alonso-Virgós et al., 2020) proved that there were "learned" behaviors, both for users and web developers, regarding page layout. A similar issue was addressed in (Isa et al., 2016), which analyzed the accessibility of the Malaysian tourism site using the Achecker evaluation tool, and developed a series of guidelines that made it possible to adapt the website and make it more accessible to people with disabilities.

The research carried out in this paper is unique due to the lack of research on websites using eye tracker focusing on the elements responsible for the availability of websites for people with visual impairment, such as farsightedness, myopia or colour blindness.

3. PROTOTYPE TEST APPLICATIONS

The WordPress tool (Narzędzie do blogowania, platforma wydawnicza i system zarządzania treścią witryny, n.d.) was used to create the first application, which allowed the maximum fulfilment of WCAG guidelines and thus managed to minimize the number of errors during testing with the WAVE tool. Wordpress made it easy to manage the content and modify elements directly in the code or with the use of appropriate plugins. The second application was created using three web technologies: HTML hypertext markup language, CSS stylesheet and PHP language. Such a choice was dictated by the desire to gain more control over each fragment of the website, which was important when examining the arrangement of elements.

3.1. Service for testing the contrast and size of elements

In this case, the layout of the graphical user interface has the characteristic features of an Internet information service which contains the most current and most important data on the home page. It is displayed as the largest tile on the page (Fig. 1). Conversely, less important or older messages are displayed below as small tiles. The website also has archival entries, a search by category and a tool for changing the size and type of font, as well as for changing the contrast of colours displayed on the page. It also allows the user to log in/create an account and add comments under articles, in the appropriate section. The user panel also offers the option of editing personal data, changing the password, profile photo and deleting the account on the website.

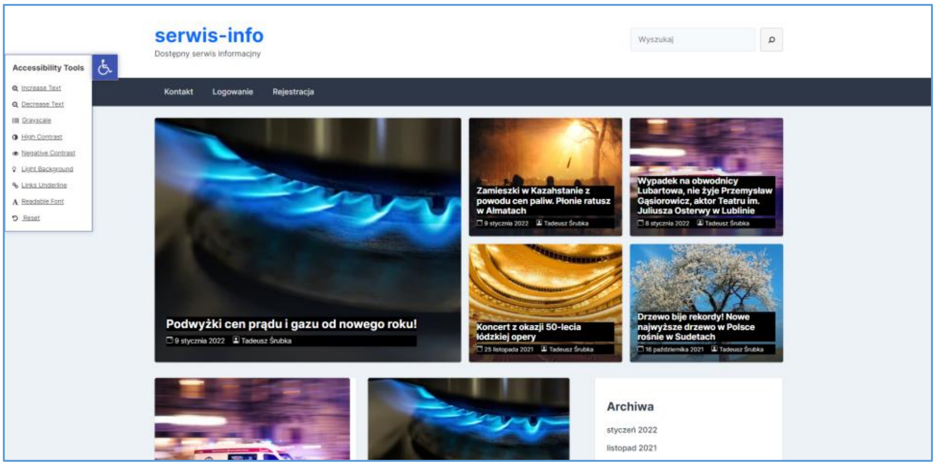

Fig. 1. The main page of the service

3.2. Service for examining the arrangement of elements

The second website has been designed in such a way that its elements responsible for the implementation of the accessibility aspects are arranged in a way resembling other, similar, most popular websites. For this version of the website, prepared in accordance with the principles of universal design (Fig. 2), a CSS file was produced, which ensured the correct arrangement of appropriate elements.

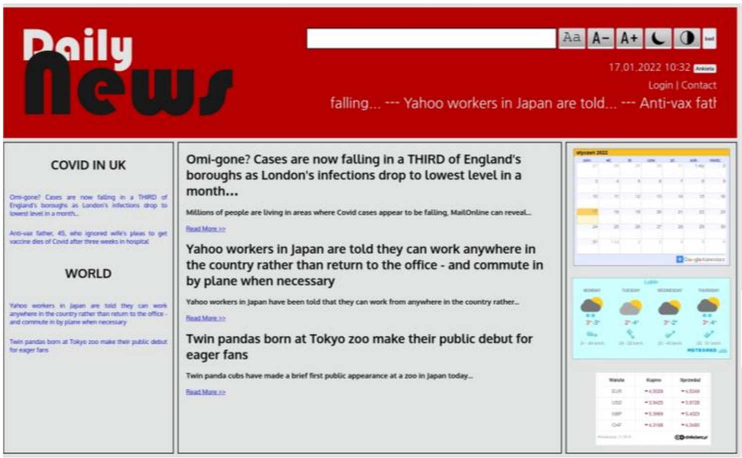

Fig. 2. Main page of UD compatible service

The version of the website inconsistent with the universal design guidelines for the arrangement of elements, created for the purpose of this study, is presented in Fig. 3.

Fig. 3. Main page of UD incompatible service

4. RESEARCH METHODOLOGY

Four experiments were conducted to investigate the quality and accessibility of the web application interface. Two of them involved the use of the eye tracker tool to examine the contrast and the placement of elements on the page. The next one was to use the WAVE validator to verify errors and irregularities according to the WCAG 2.0 standard. For the last study, the LUT (Lublin University of Technology) checklist (Miłosz, 2014) was used, by means of which a subjective assessment of the quality of the analyzed websites was made. Four websites were used for the study. Three developed for the purposes of the research. The first two (Fig. 1 and 2) were compatible with the UD guidelines, while the third one (Fig. 3) was not. The fourth website, available in the Internet (TVP Info, n.d.), also was not compatible with the UD guidelines.

Twenty students of Computer Science with extensive experience in designing and implementing applications participated in the study. All of them took part in the eye tracking study. The participants were divided into two separate groups for assessment of the interfaces using the LUT checklist. They assessed the websites that were and were not compliant with the Universal Design guidelines. Ten of the participants had visual impairments: farsightedness, myopia and colour blindness. They all signed the consent for the study.

4.1. Assessment methods

The first part of the experiment was performed using the Gazepoint GP3 HD eye tracker (GP3 HD Eye-Tracking Device – Take Advantage Of Research-Grade Equipment, n.d.), which uses a camera to monitor the activity of the eyeball (blinks, stops or fast movements) at a frequency of 150 Hz. The iMotions 9.0 (iMotions: Unpack Human Behavior, n.d.) software was used to do the research using the eye tracker. Each participant was shown charts with instructions and individual views of the tested visualizations. The task of the participants was to locate specific elements. The data obtained from the experiment were exported and a statistical analysis was conducted. The measures used in the study were: the number of fixations, fixation duration and the time to the first fixation. Each participant completed 10 tasks for each website.

In the second part of the study, each participant, in order to get acquainted with the websites, received a list of eleven commands to be executed, the content of which was related to the interfaces of two sites with UD and without UD principles. The commands concerned the layout of the interface components and the GUI transparency. Based on their experience, after interacting with websites, they filled in the LUT checklist, using a rating scale from 1 to 5. This measure is based on the Nielsen heuristics. The WUP measure was calculated from the obtained results (Miłosz, 2014).

To determine the availability of websites, the Internet tool "wave.webaim.org" was used to analyze the compliance of websites with the WCAG guidelines. Additionally, this tool allowed to verify the level of the website and set the direction of actions to improve the website / web application. The validator indicated errors that were often unnoticeable and could seriously affect the functioning of the website. The choice of the WAVE tool was preceded by thorough analyses of similar solutions, and was determined by such issues a high assessment of specialists, a wide spectrum of analysis (not only HTML and CSS validation), free license, an attractive way of presenting results, the verification of the correctness of the source code and contrast testing. The research was carried out by two independent experts in the field of universal design and computer science.

5. RESULTS

The first part of the experiment involved conducting an eye tracking study. Each participant was displayed alternately a panel with the content of the task to be performed (Tab. 1) and a view of the website. The static analysis was performed with the use of libraries and a tool created in the R language. In order to verify whether the distribution of the samples is similar to the normal distribution, the Shapiro-Wilk test was performed. Additionally, the Levene's test and the Student's t-distribution were performed to see if the data were significantly different.

Tab. 1. Set of tasks to study contrast, size and placement of elements using an eye tracker

Task no.	Contrast	Size of elements	Element placement
1	Locate the item to search for.	Locate the "Contact" tab.	Locate the item that allows you to print the article.
2	Locate the comments section.	Locate the article tags.	Locate the item with user comments.
3	Locate the article tags.	Locate the article category.	Locate the login button item.
4	Locate the news service department/editorial section in the contact tab.	Locate the source of the article.	Locate the item with the currency rate widget.
5	Locate the article publication date field.	Locate the "Culture" categories in the Category Selection section.	Locate the item that allows to turn on the night mode.
6	Locate the source of the article.	Locate the author of the article.	Locate the item with a bar with scrolling article titles.
7	Locate the “Culture” categories in the Category Selection section.	Locate the item to search for.	Locate the item with the contact number.
8	Locate the “Poland” categories in the Category Selection section.	Locate the "Poland" categories in the Category Selection section.	Locate the marked location on the map.
9	Locate the author of the article.	Locate the comments section.	Locate the location of the registration button.
10	Locate the "World" categories in the Category Selection section.	Locate the article published date field.	Locate the location of the password field.

5.1. Eye tracking study – the Time to the First Fixation

The Time to the First Fixation (TTFF) determines the average time to localize a specific area of interest (AOI). This indicator provides information on how specific aspects of the visual scene are prioritized. This metric is useful for evaluating the performance of two or more areas on the same website, application interface, or for comparing similar GUI elements (iMotions: Unpack Human Behavior, n.d.). A short TTFF means that the searched element was found quickly and indicates its strong visibility through, for example, flashy colour, location in the center of the screen, a large size or visual differentiation from other objects. A longer TTFF may be due to the fact that a given element is not located in the typical place or it is only slightly visible. In Tab. 2. the TTFF was presented for contrast study, on pages with and without UD guidelines.

Tab. 2. TTFF for page contrast study

	UD website Time *(ms)*	No-UD website Time *(ms)*
Screen 1	556.8	3546.8
Screen 2	120.3	3657.0
Screen 3	591.3	5043.0
Screen 4	897.0	5692.0
Screen 5	627.5	3436.8
Screen 6	524.5	2828.1
Screen 7	919.2	3191.5
Screen 8	1150.3	4940.5
Screen 9	732.4	3259.4
Screen 10	1298.6	3690.1
Mean	741.79	3928.52
Variance	115107.325	899549.006
Standard deviation	339.274	948.445
Confidence intervals	210.281	587.841
Shapiro-Wilka test	0.869	0.090
Levene's test		0.09296116
T-test		$8.872 * 10^{-9}$

The next step was to examine the influence of the element size on two separate websites on the searching time for an element in the GUI. The results are presented in Tab. 3.

Tab. 3. TTFF for size of elements on page study

	UD website Time *(ms)*	No-UD website Time *(ms)*
Screen 1	780.6	4549.3
Screen 2	438.9	2357.1
Screen 3	877.1	5187.6
Screen 4	528.4	3948.8
Screen 5	838.6	3312.5
Screen 6	673.5	1601.1
Screen 7	651.4	3762.3
Screen 8	810.5	2693.2
Screen 9	549.9	3597.7
Screen 10	579.1	2631
Mean	672.8	3364.06
Variance	22190.375	1155253.394
Standard deviation	148.964	1074.827
Confidence intervals	92.327	666.172
Shapiro-Wilka test	0.635	0.992
Levene's test		0.001565083
T-test		$2.084 * 10^{-5}$

To analyze the influence of the arrangement of elements, tests were performed on two created services. The results of these tests are presented in Tab. 4.

Tab. 4. TTFF for placement of elements on page study

	UD website Time *(ms)*	No-UD website Time *(ms)*
Screen 1	2171.9	5021.3
Screen 2	655.1	1483.4
Screen 3	1541.1	6872.1
Screen 4	1196.8	2531.8
Screen 5	741.3	4488.1
Screen 6	789.7	4937.1
Screen 7	2236.4	5417.2
Screen 8	638.0	2693.3
Screen 9	1509.3	4819.7
Screen 10	512.6	4593.5
Mean	1199.22	4285.75
Standard deviation	640.7257	1592.372
Variance	410529.441	2535648.596
Confidence intervals	397.1186	986.9442
Shapiro-Wilk test	0.4365	0.1032
Levene's test		0.1366
T-test		$2.16 \cdot 10^{-5}$

A significant time difference can be noticed in locating all test items in all views used in the experiment. The results of the statistical analysis show that the samples have a normal distribution, however, the samples in the size tests have a non-uniform variance, and the samples in the contrast tests have a homogeneous variance. This means that the analysed samples differ significantly between the websites with and without universal design guidelines.

5.2. Eye tracking study – the number of fixations

The number of fixations is correlated to the total dwell time (Holmqvist et al., 2011). The higher the total number of fixations, the lower the participant's search ability or the worse the structure of displayed stimuli. This means that if the informativeness of stimuli is high (in other words, the structure of stimuli supports the information retrieval process), the number of fixations decreases (Grobelny et al., 2006).

Then, the analysis of the number of fixations for services in individual tasks was carried out. For the results, the mean, standard deviation, variance and confidence intervals were determined, and the Shapiro-Wilk, the Levene's and the t-Student tests were performed. The results for the study of the contrast, size and distribution of elements are presented in Tabs. 5, 6 and 7, respectively.

Tab. 5. Fixation number for the page contrast study

Scr.	UD website					No-UD website					Levene's test	T-test
	Mean	Std. dev.	Variance	Conf. int.	Shapiro-Wilk	Mean	Std. dev.	Variance	Conf. int.	Shapiro-Wilk		
1	4.25	2.022	4.092	0.886	0.2932	13.75	6.773	45.881	2.968	0.1821	0.2873	$5.517*10^{-7}$
2	7.9	4.089	16.726	1.792	0.0861	16.4	8.556	73.200	3.750	0.1593	0.6547	$2.752*10^{-4}$
3	5.95	2.928	8.576	1.283	0.08333	13.65	6.149	37.818	2.695	0.1545	1	$1.115*10^{-5}$
4	11.1	8.668	75.147	3.799	0.0609	25.95	10.708	114.681	4.693	0.0650	0.7282	$2.324*10^{-5}$
5	7	4.267	18.210	1.870	0.3782	15.9	6.307	39.778	2.764	0.0991	0.4259	$6.525*10^{-6}$
6	5.85	2.996	8.976	1.313	0.3123	16.15	9.343	87.292	4.094	0.0512	0.5738	$3.428*10^{-5}$
7	6.75	3.275	10.724	1.435	0.5321	19.05	10.555	111.418	4.626	0.0763	0.3990	$1.425*10^{-5}$
8	6.7	3.840	14.747	1.683	0.3627	18.6	8.543	72.989	3.744	0.0512	0.4630	$1.556*10^{-6}$
9	5.95	2.724	7.418	1.194	0.2119	16.5	6.939	48.157	3.041	0.0552	0.7548	$2.016*10^{-7}$
10	7.95	4.236	17.945	1.857	0.2455	15.4	7.576	57.410	3.320	0.0558	0.9282	$4.551*10^{-4}$

Tab. 6. Fixation number for size of elements on the page study

Scr.	UD website					No-UD website					Levene's test	T-test
	Mean	Std. dev.	Variance	Conf. int.	Shapiro-Wilk	Mean	Std. dev.	Variance	Conf. int.	Shapiro-Wilk		
1	7.6	2.186	4.778	0.958	0.434	18.65	5.742	32.976	2.516	0.35	0.834	$1.002*10^{-9}$
2	5.2	2.261	5.115	0.991	0.144	17.7	6.821	46.536	2.989	0.216	0.207	$2.233*10^{-9}$
3	11.95	6.27	39.313	2.747	0.227	20.2	8.799	77.431	3.856	0.142	0.673	$1.532*10^{-3}$
4	6.6	1.569	2.463	0.687	0.218	19.2	10.149	103.01	4.448	0.17	0.738	$2.879*10^{-6}$
5	6.95	1.19	1.418	0.521	0.112	17.7	8.202	67.273	3.594	0.422	0.464	$1.068*10^{-6}$
6	6.3	2.273	5.168	0.996	0.115	16.95	4.999	24.997	2.191	0.176	0.575	$1.532*10^{-10}$
7	5	2.555	6.526	1.120	0.402	13.6	6.193	38.357	2.714	0.215	0.742	$1.291*10^{-6}$
8	5.5	1.504	2.263	0.659	0.153	17.25	7.202	51.881	3.156	0.081	0.938	$1.585*10^{-8}$
9	6.7	3.294	10.853	1.444	0.151	18.7	10.250	105.063	4.492	0.746	0.746	$1.393*10^{-5}$
10	5.1	1.889	3.568	0.827	0.368	15.9	8.528	72.726	3.737	0.078	0.202	$2.515*10^{-6}$

Tab. 7. Fixation number for placement of elements on the page study

Scr.	UD website					No-UD website					Levene's test	T-test
	Mean	Std. dev.	Variance	Conf. int.	Shapiro-Wilk	Mean	Std. dev.	Variance	Conf. int.	Shapiro-Wilk		
1	8.4	4.453	19.831	1.952	0.1635	11.55	3.394	11.523	1.487	0.0756	0.7573	0.0162
2	7.45	3.605	12.997	1.580	0.5233	10.35	4.568	20.871	2.002	0.0868	0.0314	0.0318
3	6.95	3.845	14.786	1.685	0.4442	9.85	3.232	10.45	1.416	0.4293	0.2085	0.0138
4	7.2	4.456	19.853	1.953	0.1196	10.3	2.993	8.958	1.312	0.1174	0.6147	0.0138
5	7.15	4.171	17.397	1.828	0.0558	10	2.991	8.947	1.310	0.8289	0.4082	0.0175
6	10.5	3.886	15.105	1.703	0.8084	15.3	7.138	50.957	3.128	0.1645	0.4801	0.0119
7	7.05	3.790	14.365	1.661	0.1631	9.7	2.003	4.010	0.877	0.1167	0.1648	0.0088
8	6.6	3.604	12.989	1.580	0.0909	9.4	3.235	10.463	1.418	0.6025	0.7808	0.0137
9	6.05	3.236	10.471	1.418	0.9138	8.75	3.226	10.407	1.413	0.2718	0.5531	0.0119
10	6.9	3.697	13.673	1.621	0.1472	9.8	3.412	11.642	1.495	0.6052	0.6286	0.0139

Based on the above results, a statistical analysis was analogously performed using the same tools. The results show that the data are normally distributed and that they differ significantly. In order to better understand the results, the graphs shown below have been created.

The graphs presented in Figs. 4, 5, 6, 7, 8, 9 show the number of fixations with their statistical data (quarter range, median) depending on the view for studies on contrast, size and placement of elements on the website.

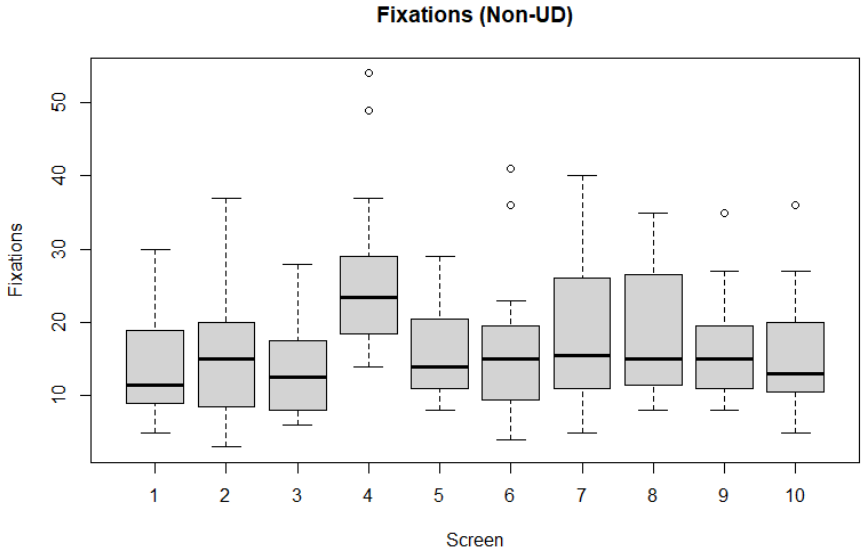

Fig. 4. Number of fixations – element contrast on the website without UD

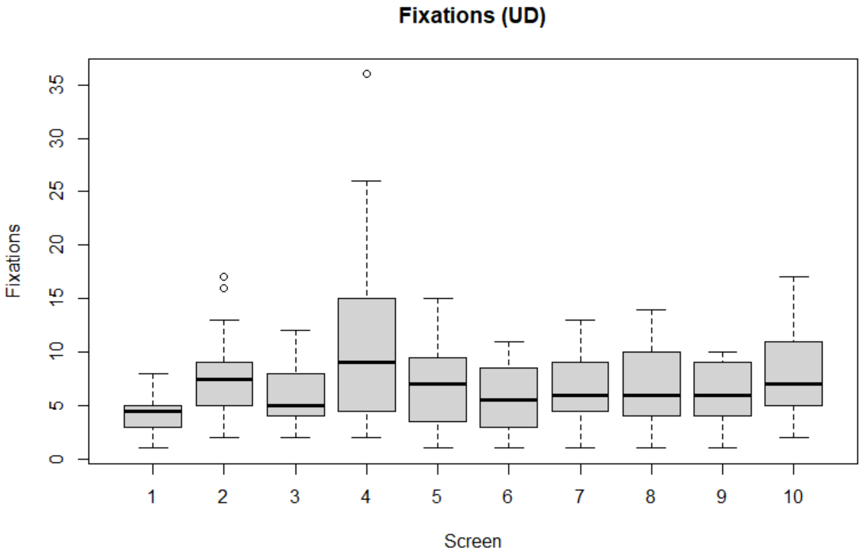

Fig. 5. Number of fixations – element contrast on the UD-enabled website

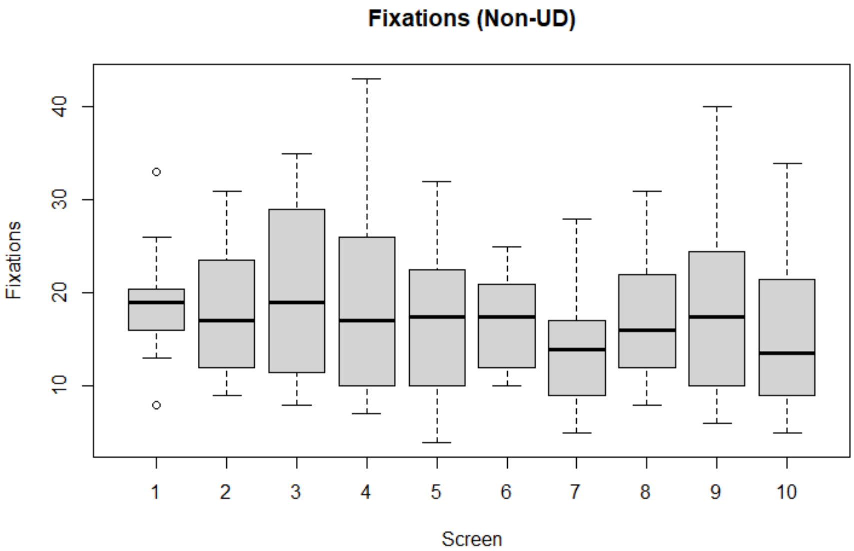

Fig. 6. Number of fixations – element size on the website without UD

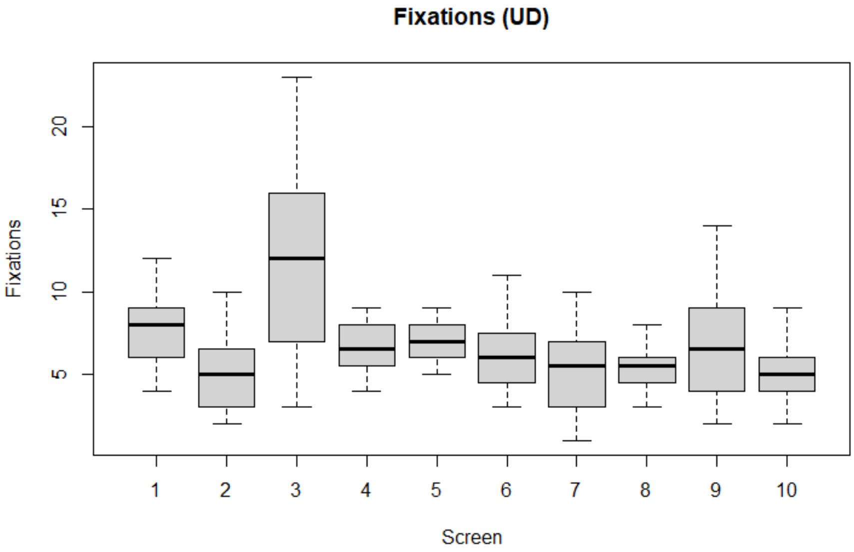

Fig. 7. Number of fixations – element size on the UD-enabled website

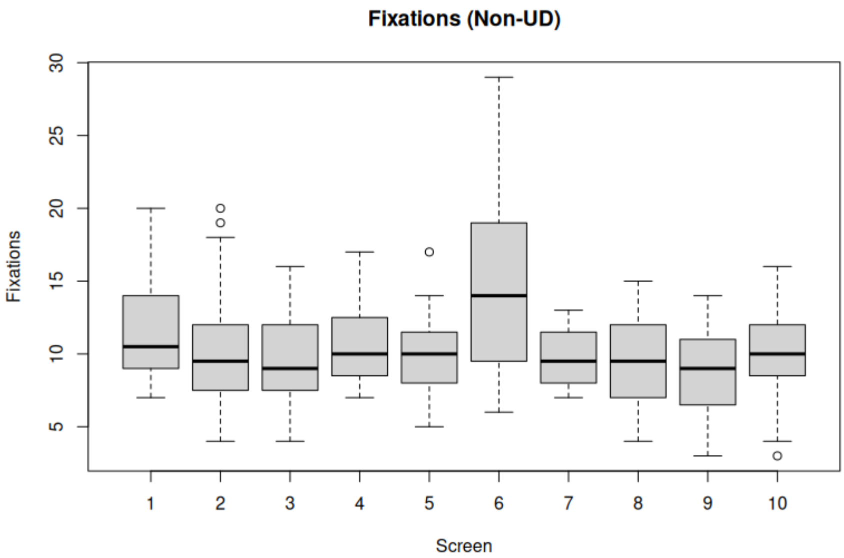

Fig. 8. Number of fixations – element placement on the website without UD

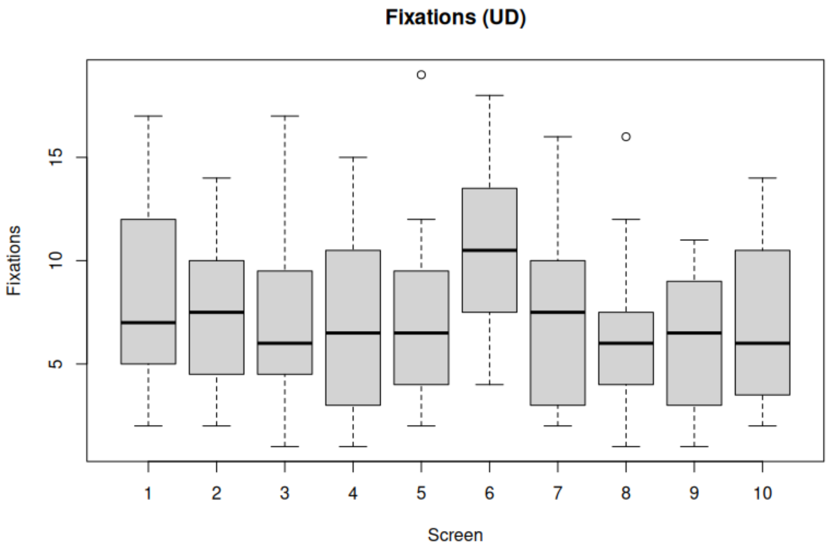

Fig. 9. Number of fixations – element placement on the UD-enabled website

5.3. Eye tracking study – fixation duration

The last analysis of the results concerned the duration of the eye fixation during the execution of the command on individual views. The results of the research and analyses are presented in Tabs. 8, 9 and 10. The duration of fixation can be applied to both individuals and groups. This measure is interesting in the analysis of various stimuli, i.e., various websites or web applications. In the case of the conducted research, the entire page area was the area of interest, and the stimulus exposure time was related to the time of finding the searched object. The interpretation of this measure may be such that the longer the fixation time, the more time the participants spent on it, which means that the displayed scene was more complicated for the respondent. Therefore, this parameter indicates the difficulty or ease of extracting information (Just & Carpenter, 1976).

Tab. 8. Fixation duration for size of elements on the page study

Scr.	UD website fixation duration *(ms)*			No-UD website fixation duration *(ms)*			Levene's test
	Mean	Std. dev.	Variance	Mean	Std. dev.	Variance	
1	2227.028	1766.995	3122270.715	5449.899	1769.524	3131214.445	0.581
2	1626.917	723.749	523813.327	5127.623	1857.711	3451091.645	0.857
3	3604.962	2010.896	4043702.245	6079.612	2051.412	4208292.572	0.207
4	1797.686	792.573	628172.486	5421.189	2640.315	6971261.691	0.257
5	1973.372	801.254	642007.503	5095.739	2147.701	4612618.320	0.535
6	1660.673	766.029	586799.958	4886.513	2715.365	7373205.503	0.548
7	1506.419	623.700	389001.543	4950.125	1959.981	3841524.830	0.903
8	2073.643	856.457	733518.380	5756.947	3622.310	13121127.490	0.228
9	2099.837	1139.046	1297425.948	5455.836	2535.253	6427506.842	0.782
10	2029.934	1576.429	2485128.774	4597.603	2274.366	5172741.132	0.428

Tab. 9. Fixation duration for the page contrast study

Scr.	UD website fixation duration *(ms)*			No-UD website fixation duration *(ms)*			Levene's test
	Mean	Std. dev.	Variance	Mean	Std. dev.	Variance	
1	1452.918	659.319	434702.145	4512.119	1886.928	3560495.866	0.484
2	2533.579	1814.358	3291894.103	4978.360	2730.994	7458329.946	0.712
3	1855.812	1194.277	1426297.826	4593.170	2625.858	6895127.762	0.954
4	3199.884	2715.384	7373309.636	7532.596	4730.115	22373987.380	0.836
5	2422.547	1342.039	1801069.752	5195.723	3177.848	10098718.730	0.825
6	1653.871	819.697	671903.248	4800.330	2172.514	4719816.377	0.928
7	2225.216	1016.202	1032667.433	5446.231	2518.568	6343187.245	0.986
8	2260.856	1366.621	1867652.940	6212.158	4636.144	21493827.830	0.479
9	1929.815	676.483	457629.680	4162.068	2687.036	7220162.087	0.541
10	2517.727	1068.469	1141626.572	4202.766	1914.743	3666240.791	0.944

Tab. 10. Fixation duration for placement of elements on the page study

Scr.	UD website fixation duration *(ms)*			No-UD website fixation duration *(ms)*			Levene 's test
	Mean	Std. dev.	Variance	Mean	Std. dev.	Variance	
1	3363.627	1966.889	3868653.098	3777.575	1645.394	2707324.495	0.8842
2	3004.432	1809.038	3272619.664	3178.353	1843.847	3399775.061	0.5235
3	2017.958	901.001	811804.268	2987.958	2094.494	4386908.777	0.3271
4	2690.388	1685.690	2841553.226	3337.922	1853.905	3436965.436	0.0350
5	2629.681	1627.812	2649772.994	2866.858	1452.316	2109224.619	0.9331
6	3860.748	2556.886	6537671.03	4762.058	2570.120	6605519.337	0.8462
7	2958.867	2297.602	5278976.192	2626.115	1170.858	1370909.47	0.9674
8	2111.905	1126.478	1268953.877	2530.234	1295.602	1678585.633	0.3995
9	2208.277	1103.397	1217486.821	2465.513	1424.831	2030144.452	0.7891
10	2543.359	1304.938	1702863.719	2802.539	1502.594	2257791.467	0.6698

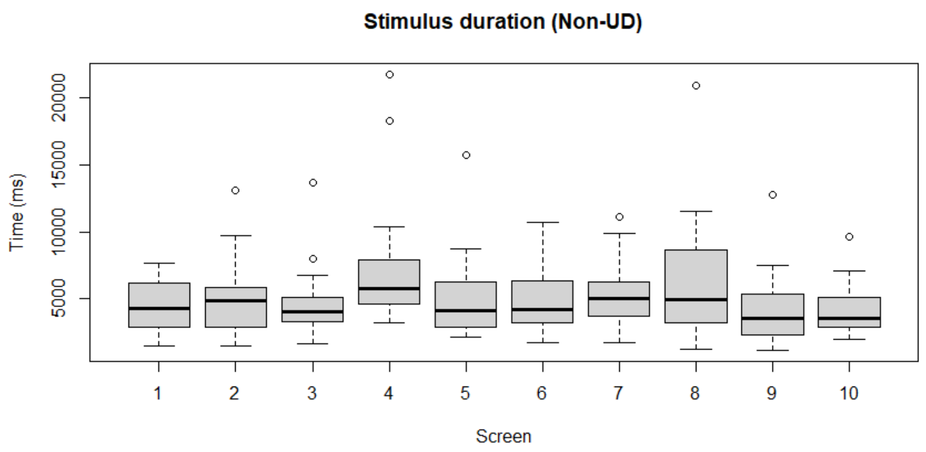

Fig. 10. Duration of fixations – element contrast on the website without UD

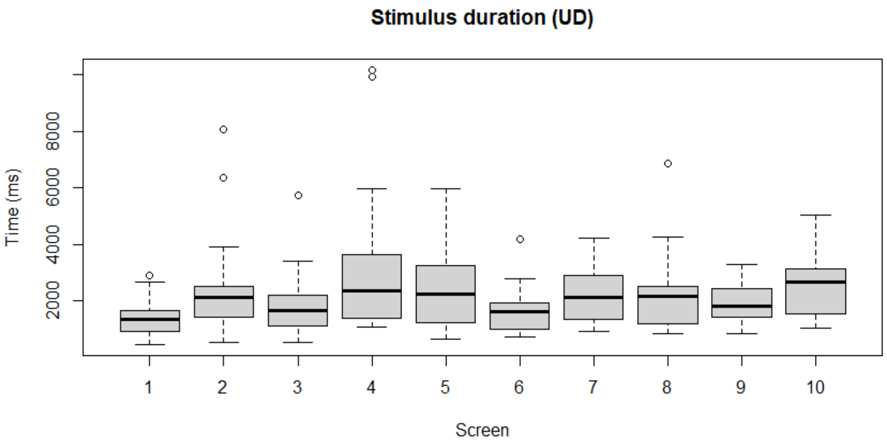

Fig. 11. Duration of fixations – element contrast on the UD-enabled website

In the analysis of the duration, in addition to the standard measures such as mean, standard deviation and variance, the Levene test was also performed, on the basis of which it can be concluded that the samples have a homogeneous variance. Only one sample has a heterogeneous variance. Similarly, as in the case of the number of fixations, due to the large amount of data, the graphs presented in Figures 10, 11, 12, 13, 14, 15 were made.

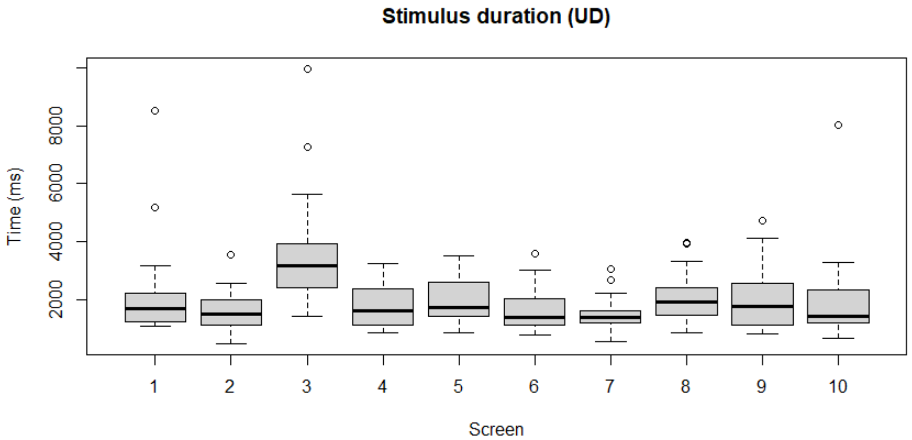

Fig. 12. Duration of fixations – element size on the UD-enabled website

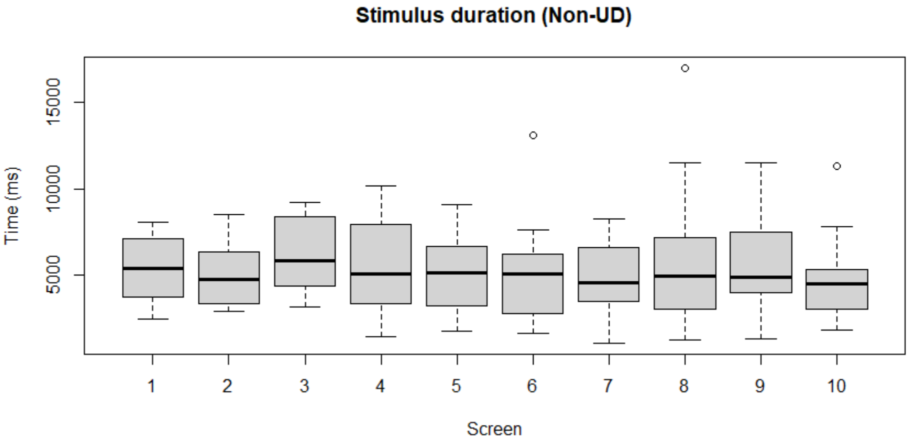

Fig. 13. Duration of fixations – element size on the website without UD

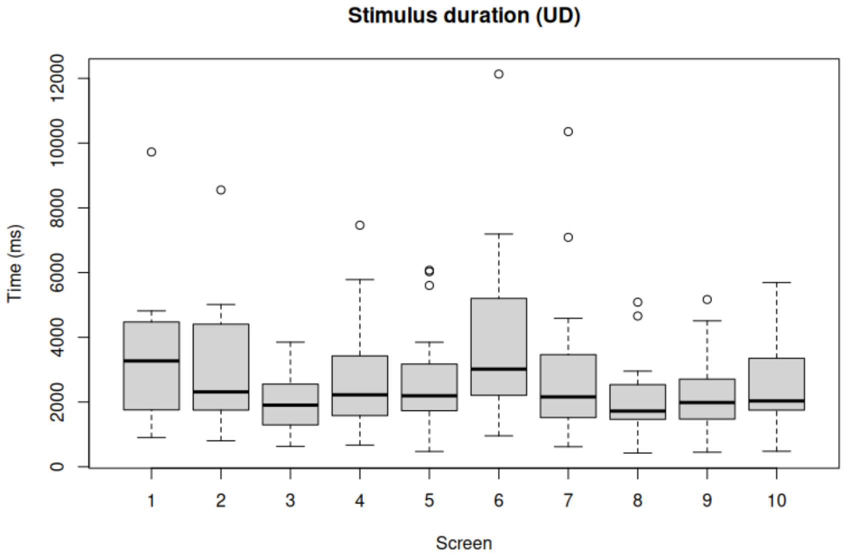

Fig. 14. Duration of fixations – element placement on the UD-enabled website

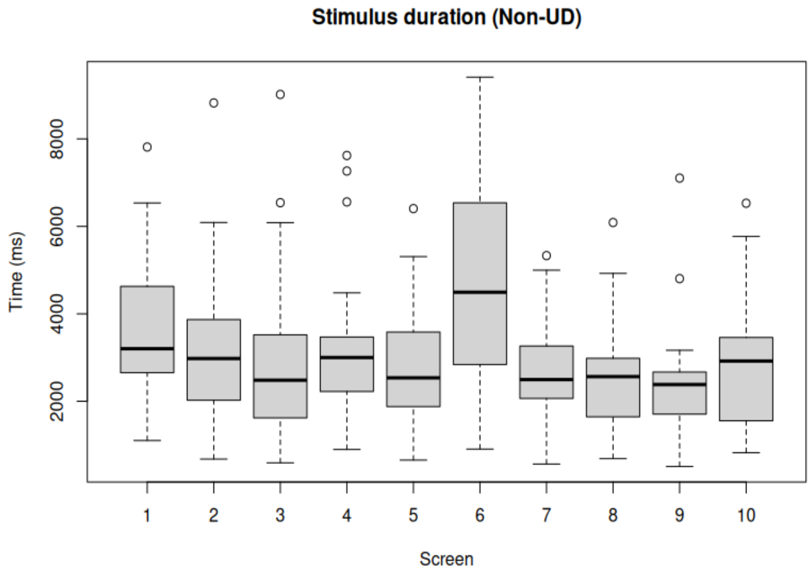

Fig. 15. Duration of fixations – element placement on the website without UD

5.4. LUT checklist

The results obtained using the LUT questionnaire were subjected to a statistical analysis, i.e. calculation of the mean, standard deviation, variance and the Levene's test. The results of the analysis are presented in Tab. 11.

Tab. 11. LUT checklist results – contrast, size and placements of website elements

Participant	WUP score of the UD-enabled	No-UD service with contrast	UD-enabled service with	No-UD service with placement
1	4.382	2.902	4.967	2.532
2	4.5	2.902	4.86	2.67
3	4.42	2.841	4.86	2.35
4	4.348	2.896	4.833	3.897
5	4.31	2.94	4.872	3.107
6	4.35	2.893	4.507	3.052
7	4.368	2.86	4.727	1.476
8	4.265	2.87	4.983	1.316
9	4.397	2.908	4.605	1.557
10	4.543	2.905	4.668	2.472
Mean	4.388	2.892	4.788	2.443
Std. dev.	0.083	0.0028	0.815	0.156
Variance	0.007	0.001	0.665	0.024
Levene's test		0.045		0.0081

In Levene's tests for all studies, the result indicated heterogeneity of variance (*p* value ≤0.05).

5.5. WAVE – the validator for automatic evaluation of web interfaces

The results of the study with the WAVE evaluation tool are graphically represented by pie charts in Figures 16 and 17.

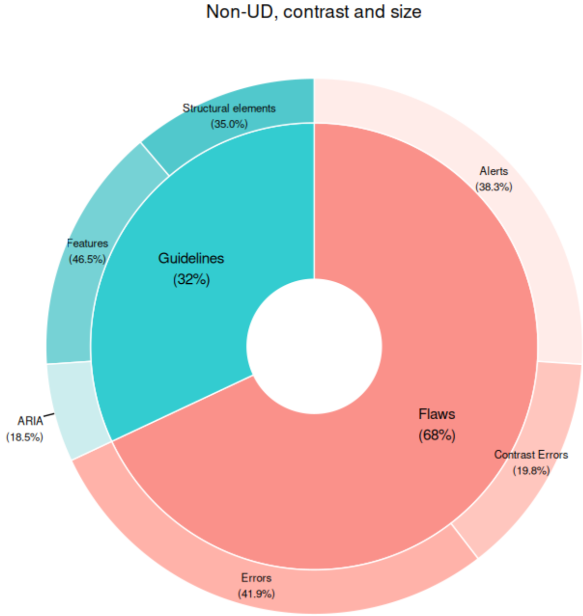

Fig. 16. WAVE analysis results chart – contrast and size of website elements without UD

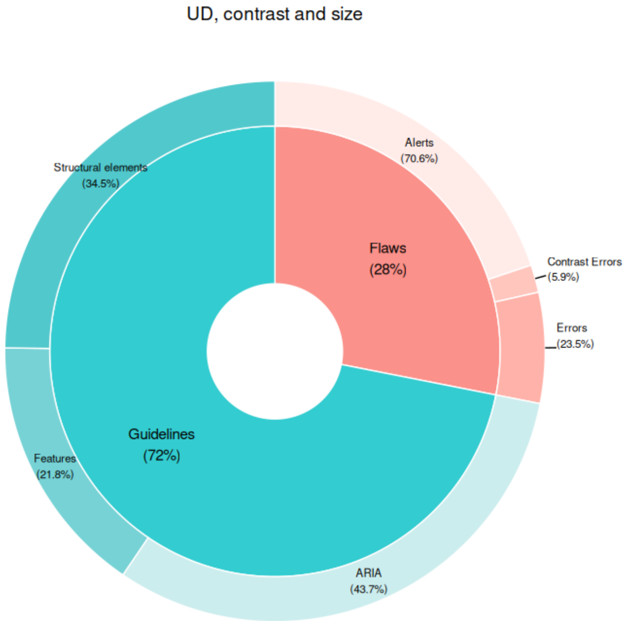

Fig. 17. WAVE analysis results chart – contrast and size of website elements with UD

6. DISCUSSION AND CONCLUSIONS

Based on the collected results of the statistical analysis, it was found that the results of the research proved the correctness of the hypotheses: "an information service limited by access barriers for people with visual impairment is worse perceived and more difficult to use than a fully accessible service" and "websites made in accordance with generally accepted principles and the universal design guidelines are more intuitive to use”.

The average time to search for an element, the duration of the eye fixation and the number of fixations on the views of websites designed according to the universal design guidelines was significantly lower by 93%, 342% and 114%, respectively (Tabs. 3-10). This indicates that the user was able to locate the selected GUI element much faster, and thus the website was easier to use and more intuitive.

The WUP indicator of the LUT checklist confirms that particular areas of websites with universal design are more useful than those that do not support these principles. In the sub-areas concerning layout and colour selection, the mean of the results was respectively higher by 80% and 137% for both websites created in accordance with universal design (Tab. 11). The smallest differences were in the areas related to entering data and forms, at the level of 34% and 72%, respectively. The participants indicate better intuitiveness, readability and accessibility of websites compliant with WCAG 2.0 standards.

Websites commonly used show a higher number of structural errors and contrast with the use of the WAVE tool (3766% and 5350%, respectively). Moreover, the ratio of errors to guidelines on the created website supporting the principles of universal design is clearly lower than on the website that does not comply with the above principles (Figs. 16, 17).

The conducted 3-element analysis confirmed that taking into consideration the principles of universal design while creating websites improves their intuitiveness, usability and accessibility. The application becomes available to a wide range of users, also to people with disabilities, e.g., with visual impairment.

The results of the research are complied with the results obtained in the analyzed literature (Acosta-Vargas et al., 2018; Ismail et al., 2020; Pivetta et al., 2013). They clearly indicate the lack of correct implementation of universal design guidelines on many popular websites.

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Conflicts of Interest

The authors declare that they have no conflict of interest.

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