Evaluating Responsive Web Design's Impact on Blind Users

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Websites complying with accessibility guidelines can be ineffective, inefficient, and unpleasant for blind users. Although the responsive-design websites investigated had acceptable levels of accessibility, they posed numerous usability barriers and triggered intense, negative user emotions.

Websites are fundamental tools for communication, information dissemination, and provision of services, particularly for the visually impaired. The web is an essential element in the social and occupational integration of people with special needs.

However, for millions of people around the world, interaction with websites and web applications can be challenging or even impossible. This challenge is due to noncompliance with accessibility guidelines. Although accessibility is a legal prerequisite in most countries, many websites currently have accessibility barriers, often making their usage impossible for people with special needs.[1] In addition, studies suggest that compliance with accessibility guidelines does not by itself guarantee a satisfactory user experience (UX) in website interaction (see the "Related Work" sidebar).[2] Even websites that comply with accessibility guidelines can become ineffective, inefficient, and unpleasant in specific situations, thus leading to problems with UX. The information and tools might be accessible, but they're neither easy nor agreeable to use.

In recent years, websites have undergone radical changes regarding design, development, and construction. Today, several aspects must be considered in web design; for example, a single design must adapt itself to different devices. This requirement resulted in the emergence of *responsive web design* (RWD), which enables website layouts to adapt to the screen resolution of the user's device.[3] This design style has become a common feature in web interface constructs. However, in responsive design, the topics of usability and UX problems for blind users have not been addressed. Thus, an investigation of the impact of this new trend on the experiences of blind users is very relevant.

In this study, we compare the emotional impact of RWD and nonresponsive web design (NWD) on blind users, based on a classification of emotional aspects during web interaction. To accomplish this objective, we selected six websites, three responsive and three nonresponsive, and asked nine users to perform six tasks on each website. The experience data of the blind users was extracted by applying the Positive and Negative Affect Schedule (PANAS) method. Using this method, we can classify users' emotions during interactions as negative affect or positive affect.

The results of this study demonstrate that although the responsive websites investigated had acceptable levels of accessibility, they posed many barriers and triggered intense, negative emotions. We conclude that the average number of negative emotional reactions is higher in the case of RWD than in the case of NWD.

Method

We performed an empirical study of RWD and NWD to evaluate the subjective attributes of blind users' experience. We adopted an exploratory approach using qualitative and quantitative indicators to understand the pragmatic phenomena of UX.

Selection of Participants

Nine blind users participated in this study. In our study, a blind user is a person suffering from complete loss of vision.[4]

We considered the length of time participants had previously used a computer. All of

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Related Work

User experience (UX) is a current approach to human-computer interaction (HCI). With a conceptual change from usability to UX, HCI professionals encounter new challenges in handling this evolution in interaction design. In recent times, researchers have focused on measuring UX in web applications, specifically with respect to the pragmatic aspects that emerge during online interactions.

An increase in the number of people with disabilities seeking access to various resources available on the web has resulted in an increased number of UX problems. UX assessment is not restricted to certain classes of users. Instead, we observed a strong trend toward universal design that aims to achieve a good UX for all classes of users. In the literature, researchers have focused on two areas: investigating the emotions of blind users by comparing the UX for accessible and inaccessible websites, and investigating UXs for new web design trends.

UX is applicable to several contexts and different purposes; however, it is mainly used in mobile platforms. For example, UX systems that address the development of new responsive interfaces have been evaluated using a participatory design method through ethnographic studies.[1]

In general, the emergence of new web trends, including responsive web design (RWD, has triggered the need for new studies to measure UX on different devices. In one study, the authors measured and evaluated the effects of RWD in UX for web system notebook and smartphone usage.[2] The results indicated that RWD for smartphones provided a better UX than RWD for notebooks. However, for most of the metrics collected in this study, UXs did not significantly differ for the two types of devices; that is, RWD had a similar effect on UXs and attitudes for both types of devices.

Another study evaluated the quality of UX on mobile devices.[3] Results showed that RWD maintains the quality of UX regarding functionality, readability, and enjoyment during interactions; however, the quality of UX deteriorates regarding information architecture.

Some studies have investigated the mood of users during interactions; they have enumerated factors related to efficiency and efficacy when confronted with barriers caused by noncompliance with accessibility guidelines.[4] One study correlated emotional aspects with efficiency and efficacy for two websites, one accessible and another inaccessible, and concluded that accessible websites achieve better results than inaccessible websites. The authors of another study investigated the correlation between emotional aspects and efficiency, and they identified the frustrations of blind users during interactions with websites and web applications.[5]

In another study, the authors presented an empirical study of the problems encountered by 32 blind users during web interactions.[6] The users performed tasks on 16 websites, yielding

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them had worked with computers for more than four years. Seven of the nine participants were male. Their average age was 33.6 years, with a standard deviation of 10.5. Six users had never attended or been involved in usability or accessibility projects.

Website Selection

We initially identified 165 websites classified into three categories: education, e-commerce, and entertainment. Of these, 107 were in the education category, 42 were in the e-commerce category, and 16 were in the entertainment category.

Criteria for selecting websites. Owing to the homogeneity of the sample of users (all blind users), two criteria were adopted for website selection. The first criterion relates to the level of compliance with accessibility guidelines. The websites must have an accessibility level greater than 5.5, according to the Web Content Accessibility Guidelines (WCAG). The second criterion is linked to the objective of this study. In each category, we chose a responsive site and a nonresponsive site to compare the two web design types. Furthermore, the difference between two sites' accessibility indexes could not be greater than 0.5.

To determine the accessibility of the tests, we used the AccessMonitor tool, which automatically generates reports of accessibility indexes according to WCAG.

Selected websites. After analyzing the initial 165 websites, we used our selection criteria to

1,383 instances of blind-user problems. Their results showed that web designs do not incorporate Web Content Accessibility Guidelines (WCAG) 2.0 correctly; further, even when the guidelines are correctly implemented, there is little indication that blind users will encounter fewer problems.

In a scientific study, researchers analyzed reports related to the main problems faced by visually impaired users when using a website.[7] They concluded that some of the problems (such as user frustration) encountered during user interactions are not addressed by accessibility guidelines; therefore, a new approach to resolve them is required. Another study reported that 45 percent of the problems encountered by the visually impaired during user interactions are related not to any violation of accessibility guidelines, but to usability and emotional aspects.[2]

Helen Petrie and Omar Kheir investigated the relationship between accessibility and usability for blind and sighted users.[8] Their results contradict previous research results. They concluded that accessibility problems are not a complete subset of usability problems, as suggested by Jim Thatcher and his colleagues,[9] nor are usability problems a complete subset of accessibility problems, as could be inferred from Ben Shneiderman.[10] The results of the study by Petrie and Kheir unveil the need for a more detailed analysis of the nature of the problems faced by blind users and sighted users, and of the problems common to both user groups.

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Table 1. Selected websites.

Category	Design	Website	Accessibility index
Education	RWD	ufal.br	5.7
	NWD	ufsc.br	5.8
E-commerce	RWD	shopfato.com.br	6.3
	NWD	fundacaodorina.org.br	6.4
Entertainment	RWD	legendasonora.com.br	6.5
	NWD	midiace.com.br	6.1

classify the websites into two subcategories: RWD and NWD. Table 1 presents the final set of websites we chose that satisfied our selection criteria.

Processes for UX Testing

Here, we present the processes used to perform UX testing. We describe the tasks that were submitted to the tests, the method to extract data, and the statistical tests for data analysis.

Table 2. Tasks by website category.

Category	Tasks
Education	Find the name and address of the university
	Find the contact email
	Find out deadline for admissions
	Find teaching and learning principles
	Find the academic calendar
	Find the login
E-commerce	Find the address of the store
	Simulate the purchase of one product
	Find the phone number of the store
	Register your email
	Simulate the simultaneous purchase of five items
	Determine whether the site is registered on social media
Entertainment	Determine whether the site is registered on social media
	Watch the first video you find for at least 30 seconds
	Find five titles that form the portfolio of videos/movies
	Use the website search tool to search for the string "Cinderella"
	Find the contact email
	Simulate sending a message through the contact form

Tasks. For UX and usability testing, we decided to perform specific tasks for each website category. There were six tasks for each site, resulting in 36 tasks for each user. Table 2 presents the tasks and their subdivisions based on the categories.

We used the assistive tool Job Access With Speech (JAWS) to perform these tasks on responsive and nonresponsive websites. We selected JAWS because all the blind users participating in the experiment had prior experience using this tool for various purposes. The order of presentation of responsive and nonresponsive websites was counterbalanced.

Data collection and extraction. In this study, data was collected through UX questionnaires. These questionnaires were designed to collect data related to users' feelings with respect to a particular set of tasks, thus allowing a study of the hedonic and pragmatic dimensions of UX. In our study, the usability and emotional attributes that emerge from user interactions with a given system are considered the pragmatic aspects of UX.[5] Thus, emotional impact is the affective component of UX and helps in the analysis of users' feelings. To measure emotional impact, we used the PANAS questionnaire, which measures 20 attributes. The 10 positive-affect attributes are as follows: interested, excited, inspired, strong, determined, active, enthusiastic, attentive, proud, and alert. The 10 negative-affect attributes are irritable, distressed, ashamed, upset, nervous, guilty, scared, hostile, tense, and afraid.

The questionnaire contains 20 questions—10 of positive affect and 10 of negative affect—providing independent measurements. This tool was developed in 1988 by David Watson and his colleagues.[6] Since its inception, this measure has been used in research for various purposes. It is popular because the instrument measures the emotional affects (in particular, depressive emotions) during user interactions.

Data analysis method. In the data analysis, we used marginal log-linear regression to compare the emotions of PANAS experienced by users while performing a set of tasks in RWD and NWD websites. To analyze the indicators that represent a set of emotions instead of analyzing each emotion separately, we used principal components,[7] which groups similar variables because they are correlated. We also used marginal log-linear regression[8] to collectively compare emotions.

We used the Spearman correlation coefficient[9] to correlate the variables from the PANAS

*Table 3. Comparison of multiple "positive affect" emotions using the marginal log-linear model.**

	Positive affect					
Design	Emotion	Average	SE	Exp(β)	CI95%	P-value
NWD	Interested	2.96	0.22	1.04	[0.86;1.25]	0.700
RWD		3.07	0.24			
NWD	Excited	2.67	0.19	1.01	[0.87;1.18]	0.858
RWD		2.70	0.20			
NWD	Inspired	2.44	0.21	1.02	[0.85;1.21]	0.866
RWD		2.48	0.20			
NWD	Strong	2.70	0.21	0.97	[0.81;1.17]	0.771
RWD		2.63	0.19			
NWD	Determined	2.93	0.21	1.01	[0.92;1.12]	0.798
RWD		2.96	0.21			
NWD	Active	2.89	0.16	0.99	[0.88;1.1]	0.819
RWD		2.85	0.21			
NWD	Enthusiastic	2.74	0.20	1.03	[0.91;1.15]	0.655
RWD		2.82	0.20			
NWD	Attentive	2.63	0.19	1.00	[0.9;1.12]	1.000
RWD		2.63	0.16			
NWD	Proud	2.56	0.23	1.03	[0.88;1.2]	0.711
RWD		2.63	0.25			
NWD	Alert	2.41	0.20	1.06	[0.98;1.15]	0.136
RWD		2.56	0.20			

SE: Standard error. Exp(β): Exponential beta. CI: Confidence interval.

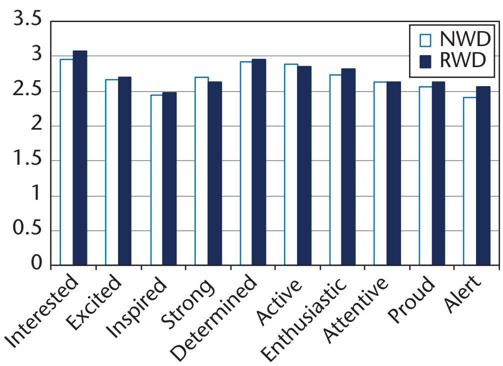

Figure 1. Comparison of the average values of positive emotions for responsive and nonresponsive web design.

questionnaires. It measures the relationship between two quantitative and nonparametric variables. In this correlation, the coefficient takes values between –1 and 1; values close to –1 indicate a strong negative correlation, values close to 1 indicate a strong positive correlation, and values close to 0 indicate no correlation.[9]

Data Analysis and Results

This section presents our analysis and results, including those related to the two main components designed for interpretation: negative-positive emotions (MC-1) and intensity of emotions (MC-2), detailed later.

Positive and Negative Affect

Tables 3 and 4 shows multiple comparisons based on the marginal log-linear model. We observed that the average value of the negative emotional reactions for responsive designs was 20 percent greater than the average value of the negative emotional reactions for nonresponsive designs; that is, the exponential beta increased by 1.20 for the average value of all the emotions. This difference was significant (p-value = 0.003). We also noted that for responsive design, the average value of scary emotions increases by 22 percent when compared with the corresponding average value for nonresponsive design (p-value = 0.007). However, regarding 18 of the emotions (interested, excited, inspired, strong, determined, active,

*Table 4. Comparison of multiple "negative affect" emotions using the marginal log-linear model.**

Design	Negative affect					
	Emotion	Average	SE	Exp(β)	CI95%	P-value
NWD	Irritable	1.41	0.12	1.11	[0.92;1.33]	0.280
RWD		1.56	0.16			
NWD	Distressed	1.19	0.09	1.06	[0.98;1.15]	0.118
RWD		1.26	0.11			
NWD	Ashamed	1.15	0.09	1.13	[0.85;1.51]	0.410
RWD		1.30	0.13			
NWD	Upset	1.11	0.08	1.20	[1.06;1.35]	0.003
RWD		1.33	0.14			
NWD	Nervous	1.30	0.14	1.03	[0.83;1.27]	0.796
RWD		1.33	0.09			
NWD	Guilty	1.04	0.04	1.04	[0.97;1.1]	0.283
RWD		1.07	0.05			
NWD	Scared	1.19	0.11	1.22	[1.05;1.41]	0.007
RWD		1.44	0.13			
NWD	Hostile	1.11	0.08	1.07	[0.87;1.3]	0.524
RWD		1.19	0.09			
NWD	Tense	1.48	0.15	1.10	[0.93;1.3]	0.263
RWD		1.63		0.17		
NWD	Afraid	1.11	0.08	1.10	[0.97;1.24]	0.128
RWD		1.22	0.10			

SE: Standard error. Exp(β): Exponential beta. CI: Confidence interval.

enthusiastic, attentive, proud, alert, irritable, distressed, ashamed, nervous, guilty, hostile, tense, and afraid) responsive and nonresponsive designs did not show significant differences. Figures 1 and 2 show the average values of the blind users' positive and negative emotions using RWD and NWD websites.

We observed that in the case of most of the positive emotions (interested, alert, excited, inspired, determined, enthusiastic, and proud) and in the case of all the negative emotions, the blind users had higher average values for responsive design than for nonresponsive design. Two emotions showed significant differences: scared and upset.

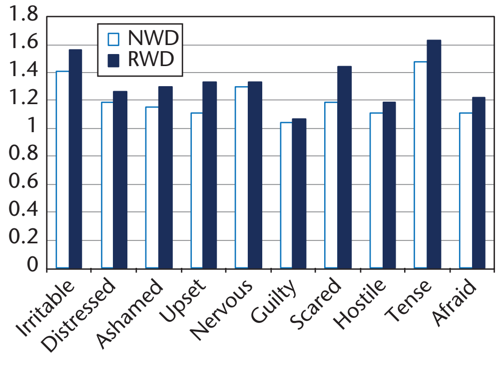

Figure 2. Comparing positive and negative emotions for responsive and nonresponsive web design.

Spectrum and Intensity of Emotions

To use indicators that represented a set of emotions instead of handling each emotion separately, we used the principal components method.[7] Table 5 shows the weights we assigned to the principal components for the positive and negative affects. They are the weighted arithmetic mean of the negative-positive emotions, given the weights in Table 6. A lower value of MC-1 indicates an emotion that is more negative (angry, anxious, alert, embarrassed, upset, nervous, scared, hostile, tense, and frightened) and less positive (interested, excited, inspired, confident, determined, alert,

Table 5. Weight of main components based on positive and negative affects using PANAS.

Variables	Weight of negative-positive emotions (MC-1)	Weight of intensity of emotions (MC-2)
Interested	0.240	0.212
Irritable	−0.243	0.156
Distressed	−0.269	0.241
Alert	−0.033	0.238
Excited	0.281	0.226
Ashamed	−0.228	0.232
Upset	−0.248	0.231
Inspired	0.266	0.221
Strong	0.243	0.118
Nervous	−0.146	0.227
Guilty	−0.132	0.111
Determined	0.191	0.296
Scared	−0.228	0.262
Active	0.156	0.221
Hostile	−0.218	0.184
Tense	−0.214	0.208
Enthusiastic	0.276	0.233
Attentive	0.228	0.243
Proud	0.248	0.251
Afraid	−0.231	0.270
Explained variance	30.9%	25.1%

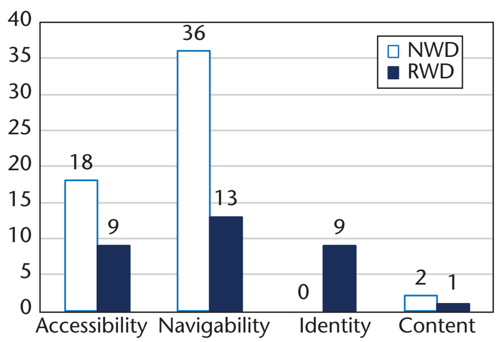

Figure 3. Measuring task performance. This shows the number of errors encountered by users during interactions.

enthusiastic, dynamic, strong, and proud), whereas a higher value of MC-1 indicates an emotion that is less negative and more positive. Higher values of MC-2 indicate higher intensities of emotion. The two principal components reported here were used to measure 56 percent of all the emotions that users displayed (30.9 percent considering MC-1 and 25.1 percent regarding MC-2) and thus showed good performance.

The indicators MC-1 and MC-2 can be considered a weighted average of emotions. The established indicators are standardized variables such as mean and standard deviation. Positive values of MC-1 indicate that the positive emotions are greater than the negative emotions, whereas negative values of MC-1 indicate that the positive emotions are less than the negative emotions. Positive values of MC-2 indicate that the evaluations of the intensity of all the emotions were above average, and negative values indicate that the evaluations of the intensity of all the emotions were below average.

Table 6 compares the MC-1 and MC-2 indicators for the categories of education, e-commerce, and entertainment using marginal linear regression. In the education category, MC-1 in responsive designs decreased by 1.76 when compared with the corresponding indicator in nonresponsive designs. This difference was significant (p-value = 0.042). In the entertainment category, MC-1 in responsive designs increased by 1.39 when compared with the corresponding indicator in nonresponsive designs (p-value = 0.001). The other subgroups derived from e-commerce and education did not show a significant difference between the values for responsive and nonresponsive designs.

In RWD, MC-1 in the entertainment category increased by 2.33 when compared with the corresponding indicator in the e-commerce category (p-value = 0.003). Again for RWD, MC-1 was higher in the entertainment category than in the education category (p-value = 0.000). Furthermore, in the education category, MC-2 increased by 0.75 in responsive design when compared with the corresponding indicator in nonresponsive design. In the entertainment category, MC-2 in responsive design increased by 0.60 when compared with the corresponding indicator in nonresponsive design (p-value = 0.031).

In-Depth Analysis

An analysis of the emotions showed that the occurrence of some types of frequent errors during the tasks could be related to users' emotions. For further analysis, these errors were classified into four categories: accessibility, navigability, site identity, and information architecture. Figure 3 shows the number of errors corresponding to each design.

The identified accessibility problems were caused by noncompliance with WCAG 2.0—for

*Table 6. Multiple comparisons of negative-positive emotions (MC-1) and intensity of emotions (MC-2) for responsive and nonresponsive design using the marginal linear model.**

		MC-1		MC-2	
	Design	**NWD**	**RWD**	**NWD**	**RWD**
Education	Average	0.39	−1.37	−0.91	−0.16
	SE	0.69	0.66	0.60	0.76
	Exp(β)	−1.76		0.75	
	CI 95%	[−3.45; −0.07]		[0.08;1.42]	
	p-value	0.042		0.028	
E-commerce	Average	0.04	−0.83	0.56	0.85
	SE	0.80	0.86	0.83	0.67
	Exp(β)	−0.87		0.29	
	CI 95%	[−2.99; 1.24]		[−0.79;1.38]	
	p-value	0.420		0.599	
Entertainment	Average	0.12	1.50	−0.10	0.51
	SE	0.70	0.51	0.69	0.65
	Exp(β)	1.39		0.60	
	CI 95%	[0.61; 2.17]		[0.05;1.15]	
	p-value	0.001		0.031	

SE: Standard error. Exp(*β*): Exponential beta. CI: Confidence interval.

example, the absence of links to bypass blocks of text and the lack of alternative text for images. The remaining errors were challenges or barriers encountered by users owing to UX problems related to the efficiency and efficacy of website usage.

We identified 27 accessibility errors, 49 navigation errors, nine identity errors, and three information architecture errors. By identifying the possible barriers that users encountered, we could analyze accessibility, navigability, site identity, and information architecture problems.

The access monitor tool identified the occurrence of 27 priority 1 WCAG 2.0 accessibility errors in the education-responsive, e-commerce-responsive, and entertainment-nonresponsive categories.

In the education-responsive category, links to bypass blocks of text were absent. Therefore, JAWS was unable to read the submenus of the websites, thus affecting the performance of tasks. Furthermore, the menus included characteristic elements of rich Internet applications containing inaccessible interface elements; therefore, JAWS could not access these elements.

The e-commerce-responsive and entertainment-Nonresponsive categories lacked alternative texts for some pictures. The existence of alternative texts for images allows information to be displayed in various ways. The lack of content in the HTML "alt" attribute made it impossible for users to perceive information through the assistive tool, thus making the information inaccessible.

An in-depth analysis showed that approximately 69 percent of the barriers encountered by blind users were related to UX problems that concerned site usage effectiveness and efficiency; examples of these problems were user disorientation, lack of context, and unclear relations among interface elements. However, we observed that the vast majority of navigation barriers were directly related to accessibility problems—that is, problems affecting interactions such as navigation, information access, and task understanding in both responsive and nonresponsive designs.

A correlation between the main barriers encountered during interactions and their emotional impact revealed that in RWD, approximately 62 percent of the barriers were caused by UX problems related to the effectiveness and efficiency of site usage; for example, the website search engine directed users to another site, thus resulting in a loss of the site identity and disorientation for the user. Table 7 presents the correlations between the emotional aspects identified during interactions and the barriers

Table 7. Spearman correlations between the positive and negative affects and barriers identified during interactions.

	Barriers or errors		
Emotions	**Navigability**	**Site identity**	**Information architecture**
Interested	−0.02	0.00	−0.05
Irritable	0.18	0.00	0.00
Excited	−0.03	0.00	0.00
Distressed	0.15	0.06	0.06
Inspired	0.00	−0.25	−0.32
Ashamed	0.19	0.00	0.00
Strong	−0.27	−0.08	−0.27
Upset	0.15	0.17	0.17
Determined	−0.19	0.00	0.00
Nervous	0.23	0.00	0.07
Active	−0.12	−0.02	0.00
Guilty	0.00	0.00	0.13
Enthusiastic	−0.18	0.00	0.00
Scared	0.00	0.00	0.18
Attentive	0.00	−0.15	0.00
Hostile	0.00	0.00	0.00
Proud	0.00	0.00	−0.17
Tense	0.23	0.00	0.00
Alert	0.00	−0.01	−0.04
Afraid	0.15	0.00	0.00

that are classified as UX problems related to the effectiveness and efficiency of site usage.

From Table 6, we observe that a lower level of interest in individuals resulted in a higher level of navigability and information architecture barriers encountered during interactions. An individual who encountered more navigability barriers during interactions was less excited, confident, determined, and alert.

Also, as the number of navigability barriers during interactions increased, the individual became more distressed, embarrassed, upset, nervous, tense, frightened, and angry. As the navigability, identity, and information architecture barriers increased, the individuals felt less safe. Some emotions, such as hostility, were not correlated with the barriers identified during interactions.

The navigation problems were the most prominent ones. Most of the navigation errors encountered were caused by user disorientation on the websites. The disorientation aspect was verified to have a strong correlation with users' negative emotions. Furthermore, the users got lost more frequently in responsive design. This observation corroborates earlier findings regarding the experiences of blind users,[10] indicating that narrow and deeper navigational website structures, which are commonly found in responsive design and are present in the three websites investigated in this study, are worse than most shallow and wider structures, which are more common in nonresponsive websites.

In analyzing the experience of blind users with responsive and nonresponsive web design styles, we observed variations in positive and negative emotions in both RWD and NWD. However, we found that users' emotions were more intense in responsive designs than in nonresponsive designs. This resulted in higher averages of negative emotions and indicated a higher percentage of negative emotional reactions during interactions.

After correlating emotional impact with the main barriers encountered by blind users during interactions, we concluded that several barriers faced by blind users in this new web design trend are related to UX problems, regarding website efficiency and effectiveness. These problems transcend the application of accessibility guidelines. In some cases, the barriers identified during interactions directly correlate with users' emotions; for example, as the number of navigation barriers increased, the individual became more distressed, embarrassed, upset, nervous, tense, frightened, and angry.

The RWDs investigated in this study revealed more barriers and more intense negative emotions, leading to low acceptance rates. Thus, although the designs are in accordance with WCAG 2.0, which represents acceptable accessibility levels, the results of this study show evidence that RWD does not provide a satisfactory UX for blind users. Therefore, we must further investigate responsive design and its impact on blind users as well as sighted users, in order to enhance responsive design and adapt it to a universal design. **MM**

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