Advance Access publication on 9 August 2017
doi:10.1093/iwc/iwx013

Adapting the Web for People With Upper Body Motor Impairments Using Touch Screen Tablets

XABIER VALENCIA[1,*], J. EDUARDO PÉREZ[1], MYRIAM ARRUE[1], JULIO ABASCAL[1], CARLOS DUARTE[2] AND LOURDES MORENO[3]

[1]*EGOKITUZ: Laboratory of HCI for Special Needs, University of the Basque Country (UPV/EHU), Informatika Fakultatea, Manuel Lardizabal pasealekua 1, E-20018 Donostia (Gipuzkoa), Spain*
[2]*Departamento de Informática, Faculdade de Ciências, Universidade de Lisboa Edifício C6, Campo Grande, 1749-016 Lisboa, Portugal*
[3]*Computer Science Department, Universidad Carlos III de Madrid, Avda. de la Universidad Nº 30, Edificio Sabatini, 28911 Leganés, Spain*
**Corresponding author: xabier.valencia@ehu.eus*

People with disabilities frequently use the Internet to perform a variety of common activities; however, they may often encounter aggravated accessibility barriers when using mobile devices to access the Web. In order to alleviate the problems faced by this group when using mobile devices, we have extended a previously developed transcoding-based system that adapts non-accessible web pages to the needs of specific users in order to enhance their accessibility. In this version, we included new adaptation techniques gathered from the literature in order to apply transcoding techniques to mobile devices. The enhanced system was evaluated with eight users with reduced mobility using tablets. The exploratory study suggests that alternative interaction methods such as the ones named 'end tap' and 'steady tap' are beneficial for some participants with reduced mobility, dexterity or strength in the upper limbs. Other results show that six of the eight users preferred the adapted version with enlarged interaction elements which required less physical effort, even if this adaptation increases the size of the page with the disadvantages associated with such a change.

RESEARCH HIGHLIGHTS

- Introduction and evaluation of a web transcoding system that adapts web pages for people with motor impairments who use touch screen devices.
- Tagging the target websites with an extension of the WAI-ARIA mark-up language enabling web transcoding.
- From the evaluation, transcoded pages were revealed to be the preferred option for most of the participants, as they require less physical effort.
- Participants were classified in function of the type and size of finger movement for target selection on touch screen devices, in order to evaluate the performance of diverse alternative interaction methods or gestures.
- Alternative interaction methods were tested by motor impaired users: 'end tap' and 'steady tap' proved to be helpful for people with less finger movement control.

Keywords: adaptation and personalization; web-based interaction paradigm

Editorial Board Member: Dr. Fabio Paternò

Received 9 September 2016; Revised 8 May 2017; Editorial Decision 14 July 2017; Accepted 21 July 2017

1. INTRODUCTION

The Internet is an increasingly valuable tool for anyone but especially for people with physical, sensory or cognitive disabilities because it allows them to perform numerous activities relating to labour, leisure, learning, etc. that would be difficult or impossible for them in a physical environment. For this reason, it is vital that digitally provided services are accessible to as many people as possible.

It is known that people with disabilities experience difficulties when they access the web from desktop computers that are similar to the problems experienced by people without disabilities using mobile devices (Yesilada *et al.*, 2011). Evidently, people with motor disabilities are faced with aggravated accessibility barriers when accessing the web from mobile devices. For example, they find the icons are too small or they are not given adequate feedback from their actions. Physical buttons are frequently substituted by gestures (such as 'swipe', 'double tap' and 'pinch'), which can be difficult for people with certain types of disability (Guerreiro *et al.*, 2010; Nicolau *et al.*, 2014; Trewin *et al.*, 2013).

Developers should create pages that are accessible for all in order to alleviate or eliminate these barriers. Unfortunately, although efforts to make the web more accessible are rapidly increasing, the number of non-accessible pages is growing even faster. In addition, universally accessible pages can be problematic because a single design may not work for everyone due to the different characteristics and needs of each person.

An alternative method to enhance Web accessibility is to make existing and currently inaccessible web content accessible. Transcoding is one of the existing approaches for converting non-accessible pages into accessible ones by automatically modifying their code. The tool presented in this paper is framed in transcoding methods. In Valencia *et al.* (2013), we described how our system, based on an extension of the WAI-ARIA (2016) annotation language, adapts web pages for people with disabilities using desktop devices.

In this paper, we present the elements added to that system to enable the adaptation of web pages to touch devices, with the aim of helping people with motor restrictions in their upper limbs to access the Internet via mobile devices. For this purpose, we gathered a number of adaptation techniques from the technical literature intended to enhance the user experience of people with disabilities. The adaptation techniques found are very diverse. For instance, they propose 'to increase the size of the interaction elements' or 'to enable the possibility of performing actions (e.g. scrolling) by tap gestures'. Nevertheless, the interaction methods considered may be insufficient for some users. For this reason, in this paper we propose new interaction methods such as 'end tap', 'steady tap' or 'augment tap', to replace the traditional 'tap' gesture.

An evaluation of this system with eight users with reduced mobility allowed us to examine in detail how users select targets (e.g. finger movements or distances from where the fingers landed in or lifted from to the target). We also measured the usefulness of diverse interaction techniques in different settings.

Advantages and disadvantages of the final design after the application of the different adaptation techniques were also evaluated. Assessment was based on both quantitative metrics (such as time, number of finished tasks) and subjective metrics (such as preferences or estimation of mental workload using the NASA TLX questionnaire) (Hart and Staveland, 1988).

The following sections reviews published works devoted to the creation of personalized user interfaces. In addition, we describe some alternative interaction methods for people with reduced mobility which are used in the desktop domain because these may serve as inspiration for creating alternative interaction methods for touch screen devices.

Subsequently, the implemented adaptation techniques are described, grouping them according to the WCAG 2.0 criteria (WCAG 2.0, 2016) (see Section 3). The proposed transcoding system and the improvements made to adapt it to allow access to the Web for people with upper body impairments are detailed (see Section 4). Finally, the adaptations made and the alternative interaction methods included in the tool are evaluated (Section 5), analysed (Section 6) and discussed (Section 7). Some conclusions are presented in Section 8.

2. RELATED WORK

User interfaces can be adapted to the needs of users and to the devices' characteristics in design-time or in run-time adaptation. Languages such as UIML, MARIA XML or UsiXML allow the definition of abstract interfaces in design time. Final user interfaces are generated in runtime, creating a user and device-adapted interface (Abram's *et al.*, 1999; Limbourg *et al.*, 2004; Paterno *et al.*, 2009). These languages can also be used to generate user interfaces in runtime. For instance Ghiani *et al.* (2014) present a system that transforms web pages to MARIA by means of machine learning techniques and subsequently it tailors them to the user.

An example of design-time adaptation is SUPPLE (Gajos and Weld, 2004). The developer creates a declarative description of the interface, device and user model in the design process. Following this, the system creates the final user interface based on functions that take into account the restrictions imposed by the input device, the user and the interface specifications. Although languages of this type are very promising they are not widespread because designers are often reluctant to use them due to the extra requirements of expertise and time.

Our system is a run-time tool that uses adaptation techniques (that is, models or templates) to automatically generate tailored user interfaces. It is applied to enriched web pages, typically present in the semantic Web. Previous annotation of web pages is only required if the target pages are not provided with semantic tags. In the future, when the semantic web prevails, previous manual annotations will not be necessary.

2.1. Transcoding techniques

The *transcoding* techniques can be framed in the latter approach. Transcoding is a method that alters the code in runtime in order to adapt web pages to the user or to the device (Asakawa and Takagi, 2008). The *transcoder* application may be located in the web server, in a proxy, or in the client (the user device). If the *transcoder* is located in the server, the user does not need to install or configure it, but it will only be valid for those pages managed by the specific server. Conversely, when the *transcoder* is located in a proxy or a client, it can adapt any page. Transcoders implemented in proxy systems do not require installation, but they may require some configuration. Installation is required when the transcoder is on the client side. This makes it more obtrusive, but it has some advantages, such as providing better control over the final result of the adaptations (Richards and Hanson, 2004). In addition, it can interact with websites under 'secure connection', unlike the proxy version which can have problems with such connections.

One of the first transcoding systems to improve accessibility was developed by IBM Research in Tokyo. Among other features, it numbered the links and serialized the content in order to make Web pages more accessible to screen readers (Asakawa, 2005).

However, this kind of adaptation was rather limited. In order to be able to produce more thorough adaptations it is necessary to know the semantics of the page elements. Semantics can be added by means of annotations. Aurora (Takagi and Asakawa, 2000) was one of the first systems to use semantic annotation to adapt the web. This system characterized user goals by means of a transaction model. 'Adapters' were responsible for adapting the elements involved in user goals and eliminating the remaining elements. The annotation task in Aurora required the creation of a transaction model and a set of rules that applied to each web element, which turned out to be rather time consuming.

Later, Takagi *et al.* (2002) presented a system to improve Web navigation for blind people, using annotation that was made, element by element, through XPATH (2016). This system was able to propose annotations based on the similarity of previously annotated pages on the site, to alleviate some of the burden of the annotation process.

The Sadie system, also created to aid navigation for the blind, proposed a new annotation system consisting in labelling the elements as a type of menu (main menu, submenu, concertina) or assigning a priority to each of them (Harper and Bechhofer, 2007). The identification of the elements in the annotation was made through the CSS (id, class) of the site. This procedure eased the annotation process as CSS elements are used throughout the site.

Our system uses XPATH in addition to CSS when CSS is not sufficient. That is, there is no consistent semantic meaning across the site or CSS is not present. Moreover, as the annotations we proposed are based on the WAI-ARIA standard (WAI-ARIA, 2016), our system can perform a large number of adaptations in the pages that include this standard, even if they have not been manually annotated.

GAPforAPE (Mirri *et al.*, 2012) is a scripting system based on Greasmonkey (2016) that utilizes a user profile to store the preferences. The user profile is stored locally and it follows the XML-based IMS ACCLIP (2016) standard. Among other adaptations, such as CSS transformations or DOM manipulations, it also adds or modifies the scripts of a web page to improve its accessibility, for example, to avoid automatic refreshing of the page. Every time the user requests a page, the system checks if any specific script for the requested page exists, if not it applies a general script. Even if general scripts can be created, they are usually tailored to a specific web page. The application of the user profile enables the personalization of the content, but the profile is locally stored adaptations. Therefore, these preferences are lost when the user accesses the Internet from a different device. Conversely, our system stores the preferences and the user model in a server. In this way the user preferences can be used across different devices.

Akpınar and Yeşilada (2015) presented an eye-tracking experiential transcoding system that sets the role of the visual elements and detects the most common eye path in the visited page in order to transcode it. This is a highly interesting approach, although somewhat limited by the requirement of eye-tracking data which hinders its use on numerous websites.

On the other hand, references to transcoding systems specifically devoted to adapting the web to people with restricted mobility are not frequent. Among the few available, Ivory *et al.* (2003) proposed various adaptations, including the addition of navigation buttons (skip to links, back, forward), and 'making evident the focus'. Although these adaptation techniques appear useful, they do not provide any evaluation of the resulting systems.

To summarize, the transcoding tools found in the literature have complex annotation models or time-consuming annotation processes. Our system, by contrast, uses an extension of the WAI-ARIA language, which is not complex and can be efficiently applied. A large number of adaptations can be applied to pages that are previously annotated with WAI-ARIA language without requiring any further annotation. On the other hand, the annotation of CSS elements, such as ids or classes, is valid for all the web pages that share these specific CSSs. In addition, the use of XPATH expressions allows the annotation of any web page lacking CSS and WAI-ARIA.

Besides, transcoding systems found in the literature, propose a limited number of adaptations targeted to specific groups of users. On the other hand, our system can be used for diverse types of users and different devices. What is more, the granularity of the adaptation techniques and the use of an ontology to decide which adaptation should be applied, enables the easy creation of different adapted web pages, without modifying the tool's code.

2.2. New interaction methods

New methods of interaction for people with restricted dexterity to assist them in selecting targets have also been proposed for desktops devices. They include 'steady click', 'bubble cursor', 'angle mouse' and 'adaptive click and cross', among others.

The 'steady click' (Trewin *et al.*, 2006) method allows users to move the cursor away from the target to a certain distance after having clicked on it. Since the adaptation of this technique to touch screen mobile devices appears to be very useful we decided to implement the 'steady tap' version proposed by Trewin *et al.* (2013).

The 'bubble cursor' (Grossman and Balakrishnan, 2005) enlarges or reduces the size of the cursor activation area depending on the proximity of potential targets in order to allow the selection of only one target. We also included a version of this interaction method, which we call 'augmented tap'.

The 'angle mouse' changes the C-D gain depending on the angles between the samples of mouse movements (Wobbrock *et al.*, 2009). When the angle of the trajectory of the mouse does not change the C-D gain is maintained however, if the angle changes the C-D gain decreases, thus smoothing the movement of the mouse. Obviously, this technique does not work on mobile device touch screens because, unlike mouse interactions, there is no cursor path.

The 'adaptive click and cross' technique modifies both the interface and the interaction (Li and Gajos, 2014). When the links are small and close to one another, the user clicks in the target location and then they cross the target element in a circle that appears with all the possible targets. This procedure can be combined with enlarging those elements that are regularly accessed. Despite this technique appearing to be helpful for mobile devices, it can be troublesome for users who have difficulties with the 'slide' gesture.

3. ADAPTATION TECHNIQUES

Transcoding techniques convert non-accessible web pages into accessible ones by means of adaptations. In order to select the most adequate adaptation techniques for each case we searched the literature to find what problems were experienced by people with reduced mobility when interacting with touch-input mobile devices and what proposals were put forward to fix them. In addition, we complemented the set of techniques found with a number of generic guidelines to improve mobile accessibility issued by W3C/WAI (Mobile Accessibility, 2016; Mobile Web Best Practices, 2016).

Conventional gestures, such as tapping, for selecting elements or directional gestures required for scrolling or zooming can be troublesome or even impossible for some people with motor impairments (Guerreiro *et al.*, 2010; Nicolau *et al.*, 2014; Trewin *et al.*, 2013). In addition, inadequate element size or position can make the target selection even harder (Guerreiro *et al.*, 2010). Text entry is also a challenging task due to the small size of screen keyboards or the lack of edges between keys (Belatar and Poirier, 2008; Wobbrock *et al.*, 2003). Moreover, some people with motor impairments can also have other associated conditions, such as cerebral palsy, that may include vision problems.

Only adaptation techniques devoted to improving navigation (such as target selection, readability or scrolling) were undertaken for the first version of the tool, a. The implemented adaptation techniques, grouped according to the WCAG 2.0 criteria (WCAG 2.0, 2016) are discussed below.

3.1. Perceivable—information and user interface components must be presentable to users in ways they can perceive

Kane *et al.* (2009) found that some users might have problems with the contrast or the font size. These barriers are often due to the restrictions of the users but they can be also caused by environmental conditions. To ensure good contrast for the *main* content, a cream yellow background, black text, and blue links are recommended (which provides a contrast ratio of, at least, 9.41:1). In other sections of the page (*navigation, content-info, complementary, banner*) white background, and black and blue letters are recommended (which ensure a contrast ratio of 9.65:1).

With respect to the font size, in the study carried out by Trewin *et al.* (2013), participants preferred font sizes ranging from 20 pt to 56 pt. For testing purposes we established a 24 pt font size, but in future versions the users themselves will be able to choose the font size that best suits their needs.

3.2. Operable: user interface components and navigation must be operable

Guerreiro *et al.* (2010) state that objectives with a 12 mm (or larger) diameter provide good ratio size/error. For this reason, we selected 12 mm as the minimum size of the interaction elements (such as links or buttons). On the other hand, the document W3C Mobile Best Practices (2016) recommends a minimum separation, or inactive space, for small interaction elements. We added a 20 px (4.46 mm) space between links and buttons.

Regarding gestures, Trewin, Swart and Pettick (2013) found that the 'tap' gesture was easily performed by 10 users out 14. Three users had some level of difficulty and only one, encountered serious difficulties. Yet they found that only in 48% of the interactions did the finger movement begin and end in the same point (or near), which is a necessary condition for a valid 'tap'.

They also found an average distance of 17.5 mm between the target and the starting or ending point of the tapping for 28% of users. At the same time, they noticed that actions such as ‘slide’ and ‘pinch’ were difficult for a large number of users. Similarly, Nicolau *et al.* (2014) verified that directional gestures were difficult, and that the most effective interaction technique was ‘tap’ followed by ‘crossing’.

As a solution, Trewin *et al.* (2013) proposed new interaction techniques such as ‘steady tap’ or ‘end tap’. ‘Steady tap’ allows the user to select an item even if the finger moves away from the target within an established threshold. While, ‘end tap’ allows the activation of an element when lifting the finger from it. Both methods allow the selection of an item even if there are uncontrolled finger movements during the process.

Since the ‘slide’ gesture may be difficult or even impossible for some users, as attested by Trewin *et al.* (2013) and Nicolau *et al.* (2014), we introduced buttons for scrolling in order to avoid forcing people to use the ‘slide’ gesture.

Bearing in mind that lack of precision can also be a problem, we decided to increase the activation area around the position where the finger landed: ‘augmented tap’. This decreases the precision requirements for selecting the target item (Findlater *et al.*, 2010; Grossman and Balakrishnan, 2005). However, this can be problematic when there are other interactive elements close to the target. For these cases, a disambiguation list was added. The list is ordered by the distance from the finger to the targets, and from bottom to top, as shown in Fig. 1.

3.3. Understandable: information and the operation of user interface must be understandable.

The layout for the adapted website created by our system is based on the WAI-ARIA landmarks (*banner, navigation, main, content-info and complementary*), common elements being grouped as recommended by the W3C standard. The *banner* is located at the top, *navigation* elements on the left, *main* content in the middle and *content-info* at the bottom of the page. If there is any *complementary* content it is placed on the right. In addition, *breadcrumbs* were inserted into the top of the *main* content, ‘provideConsitentNavigation’.

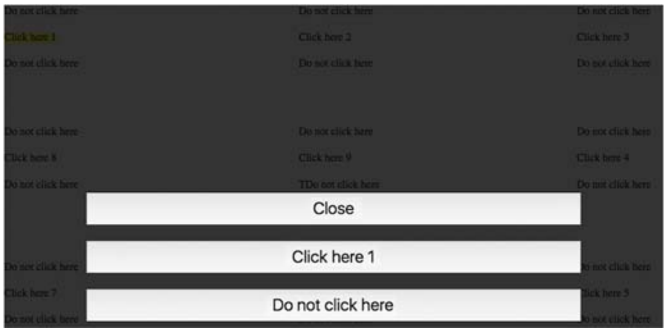


Figure 1. Disambiguation user interface for the ‘augmented tap’ method of interaction.

Finally, a technique that eliminates non-essential page elements (such as advertising or unnecessary images) was also applied in order to make the interface clearer. Figure 2 shows the page before adaptation and Fig. 3 shows the same page after applying all the adaptations techniques.

4. ADAPTATION SYSTEM

4.1. Introduction

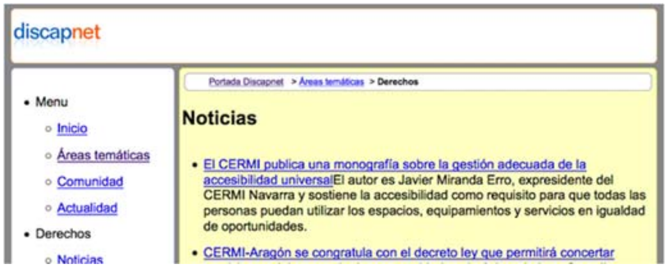
The transcoding system we presented previously (Valencia *et al.*, 2013) has substantially evolved. In order to adapt the system to the mobile environment, new adaptation techniques were added such as the ones presented in the previous section. The system makes use of an ontology (Gruber, 1993) to model adaptation techniques, the user or the web page, etc. The ontology defined in OWL (2016) was modified in order to adapt the system to the needs identified in the experiments conducted previously (Pérez *et al.*, 2014, 2015; Valencia *et al.*, 2015) and for it to work within mobile environments.

4.2. System architecture

Transcoding systems are usually classified as client, proxy or server tools depending the location in which they are placed.

El CERMI publica una monografía sobre la gestión adecuada de la accesibilidad universal
El autor es Javier Miranda Erro, expresidente del CERMI Navarra y sostiene la accesibilidad como requisito para que todas las personas puedan utilizar los espacios, equipamientos y servicios en igualdad de oportunidades.

Figure 2. Discapnet website.



- El CERMI publica una monografía sobre la gestión adecuada de la accesibilidad universalEl autor es Javier Miranda Erro, expresidente del CERMI Navarra y sostiene la accesibilidad como requisito para que todas las personas puedan utilizar los espacios, equipamientos y servicios en igualdad de oportunidades.
- CERMI-Aragón se congratula con el decreto ley que permitirá concertar

Figure 3. Discapnet website after applying the suitable adaptation techniques.

The designed system has a hybrid architecture since one module is located in the client and others are on a server:

- The Presentation Module runs on the user device (PC, mobile, tablet).
- The Adaptation and Coordinator Modules and the Knowledge Base run on a server.

The adaptation process is roughly as follows. A non-accessible page is cached by the Presentation Module and sent to the Coordinator Module. The Adaptation Module carries out the pertinent adaptations following the information collected from the Knowledge Base. Subsequently, the Presentation Module presents the modified page to the user. Figure 4 shows the process for adapting a previously annotated page and another page with the WAI-ARIA (2016) annotations already integrated.

Even if the Adaptation Module performs the adaptations, the logic of the adaptations is in the Knowledge Base. The Knowledge Base decides which adaptations are applied to specific elements, according to defined rules. This architecture enables easy creation or a set of adaptations without changing the code. For instance, it is possible to add new types of users or devices by simply updating the Knowledge Base as the Adaptation Module is agnostic with respect to both the device and the user. The different modules are explained in detail below.

4.2.1. *Presentation module*

The current implementation of the Presentation Module is an add-on for the Firefox web browser and runs on PCs, smartphones and tablets. Even if it is running as an add-on, the architecture facilitates migration to other platforms (Chrome add-on, proxy, etc.) whenever the new Presentation Module satisfies the following requirements:

- Identify the user
- Catch the web page
- Send the page to the Coordinator Module
- Get and present the modified page

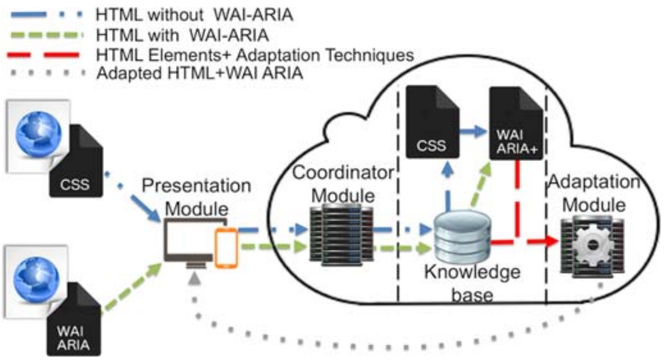


Figure 4. General architecture and workflow.

In addition to these requirements, the Presentation Module manages preferences and collects user-generated events. These events can be used to feed specific data mining programs and to detect changes in user skills, such as fatigue, deterioration, etc.

A preference manager for proposing possible preferences to the user has been implemented as a component of the Presentation Module. The changes made in the preferences are stored in the knowledge base and shown in real-time, so the user can immediately notice the consequences of the chosen option. Figure 5 depicts the preferences selection menu for enabling or disabling the scroll buttons.

4.2.2. *Coordinator module*

The Coordinator Module has an instrumental role. It was implemented as a Web service and is responsible for mediating between the various existing modules (Presentation Module, Knowledge Base, Adaptation Module), performing the following tasks:

- Establish communication with the Presentation Module
- Ask for the necessary adaptations to the Knowledge Base
- Update the Knowledge Base
- Communicate with the Adaptation Module

The Coordinator Module (see Fig. 6) first receives the page to be adapted from the Presentation Module along with the user credentials (username, password, device). Afterwards it obtains the adaptation techniques from the Knowledge Base which are suitable for the specific user, device and website.

Using this list the Adaptation Module performs the adaptations and returns the recoded page to the Presentation Module.

Each time the user preferences are modified, a request also arrives to the Coordinator Module, which then updates them in the Knowledge Base. Following this, the aforementioned process is repeated to adapt the page according to the new preferences.

4.2.3. *Knowledge base*

The system is based on a Knowledge Base, implemented in the OWL language (OWL, 2016) created with the ontology editor tool Protégé (2016), which defines the user models, the

CHRISTMAS IN THE BIDASOA (Bidasoa-

¿Do you want buttons to scroll down and up the page?

Figure 5. Bidasoa Tourism website with the preference manager user interface.

adaptation techniques, the devices, the assistive technologies and the annotation model of the web pages. Let us describe the structure (Fig. 7) and content of the ontology.

Annotation model. We extended the WAI-ARIA (2016) annotation model in order to be able to perform further adaptations. Using this model the annotator can describe the role of the interaction elements to allow the system to match the most adequate adaptations. Our system can automatically adapt pages with the original WAI-ARIA annotations but it cannot take advantage of the whole set of system features.

Among the new roles added there are 'helping roles', such as '*ContextInfo*', '*FAQ*' or '*Tutorial*', that can be used to provide help to complete a task or to clarify the operation of the element. Another new role is '*SiteMap*', to create a site map of the website when it is not available or to identify an element with such a role, when one is present. '*Caption*' indicates where the video captions are located and '*GeoMap*' provides written directions, instead of a visual map.

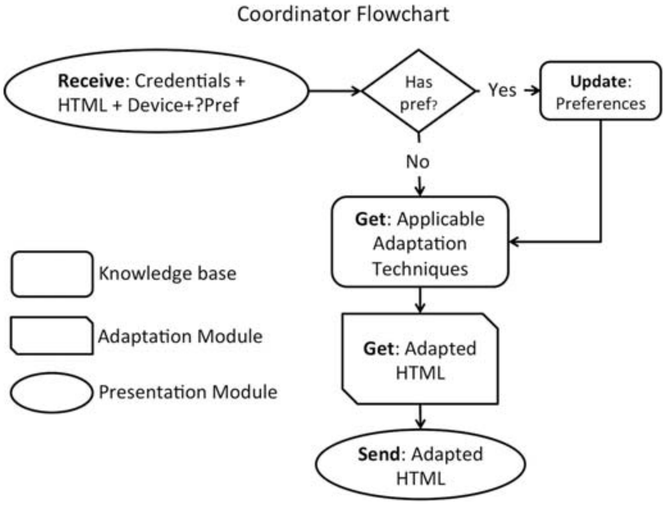


Figure 6. Coordinator module flowchart.

In addition, new properties were added: dimming, hide, stretch, remove and priority. '*Dimming*', '*hide*' and '*stretch*' can be used to hide part of the content, such as leaving only the news headings in the starting page to make it simpler and smaller. The '*priority*' property can be used to mark the elements as being necessary or otherwise for the purposes of the task or the point of view of the user, so the page can be reordered with this property taken into account. Finally '*remove*' property is used to remove those elements that can be harmful for the user. For instance, a flashing element is tagged as *remove = 'flashing'* so it would be removed when the user has photosensitivity.

Every annotated element present in the website is stored in the knowledge base in this way: firstly a reference to the website (for example *discapnetsite)*, is stored in the knowledge base as a *website* class. Then, all the website annotated elements are included as *htmlElement* class and linked with the created *website* element with a property assertion (e.g. 'discapnetsite *hasHMTLElement* discapnetFooter', 'discapnetsite *hasHTMLElement* discapnetAdvert'). After that, a role or property is assigned to the html element (e.g. 'discapnetFooter *hasRole* content-info', 'discapnetAdvert hasProperty distractor'). Finally, the html element is identified with the CSS id, the CSS class or the XPATH, with a property assertion (e.g. '*id = foot*' can be a property assertion for a page footer or 'class = publicidadGoogle' for announcement elements).

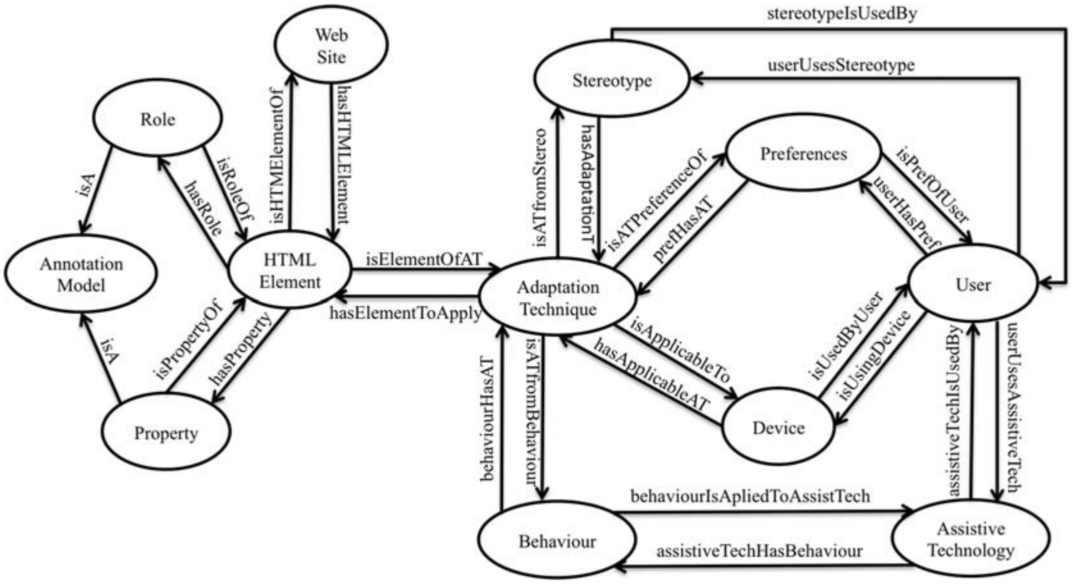


Figure 7. Simplified ontology structure and property assertions.

Adaptation techniques. The Knowledge Base models the adaption techniques but it does not implement them. In this way it decides which adaptations are applicable. Adaptations are first classified into three main groups: content, presentation and navigation adaptations (Knutov *et al.*, 2009). The parameters of adaptation techniques are defined, when necessary, by identifying the roles and properties of the annotation model. For instance, the technique 'provideConsistentNavigation' can be classified as a navigation adaptation taking the roles *banner*, *navigation*, *main*, *content-info*, *complementary* and *breadcrumb* as parameters.

To date, more than 50 adaptation techniques have been implemented encompassing font style changes, the provision of site maps, the removal of elements, etc. The approach followed enables the addition of new adaptation techniques, thus enabling system development to become a continuous process.

User model. Three general user interaction factors were included in order to build the user model *t*: cognitive (C), physical (S) and sensory (S), Table 1. A more detailed user model can be created, adding when necessary new user groups or subgroups.

Stereotypes and rules. When inferring adaptation techniques from the characteristics of a given user, inconsistencies between the adaptation techniques can appear. Stereotypes help to avoid this situation. Stereotypes are sets of predefined clusters of adaptation techniques well suited for specific user groups. To date, stereotypes for people with low vision, blind people and for people with motor impairments have been defined.

Stereotypes were created using property assertions:

'Stereotype *motImpaired* hasAdaptationTechnique *removeDistractor*'
'Stereotype *motImpaired* hasAdaptationTechnique *provideEndTap*'

Reasoning rules are used to match users with suitable stereotypes, to connect annotated web elements with adequate adaptation techniques, and to determine which ones are applicable. Rules were coded using the Semantic Web Rule Language (SWRL, 2016) for OWL. Next, some of the rules related with the *removeDistractor* and *provideEndTap* adaptation techniques are explained.

Table 1. User model classified by user interaction factors for each subgroup.

General group	Subgroup	
C	C0.1 Decline in maintaining attention	
	C0.2 Learning disabilities	
	C0.3 Language disabilities	
	C0.4 Reduced memory capacity	
P	P0.1 Limited movement	
	P0.2 Inability to use mouse	
S	S.S Sight	S.S0.1 low vision
		S.S0.2 blindness
		S.S0.3 colour blindness
		S.S0.4 photosensitivity
		S.S0.5 eye strain
	S.H Hearing	S.H0.1 hearing loss
		S.H0.2 deafness

Firstly, the elements that are part of the adaptation technique are defined with the rule:

'HtmlElement(?el), hasRemoveProperty(?el, *distractor*) -> elementIsPartOfTechnique(?el, *removeDistractors*)'

This step is not required for adaptations techniques without parameters as for example the technique *provideEndTap.*

Subsequently, the target devices for the adaptation technique are set by means of rules such as the following ones:

'Device(?d), deviceHasInput(?d, *touch*) -> isApplicable (*provideEndTap*, ?d)'
'Device(?d) -> isApplicable(*removeDistractor*, ?d)'

The former rule sets the *provideEndTap* as only applicable to devices with touch screens, such as tablets or mobiles. The later rule sets the *removeDistractor* as applicable to all the devices.

As a result, the coordinator module can use the ontology defined in this manner to gather the specific adaptation techniques and their related elements, which are suitable to adapt a concrete website.

Ontology enhancement. In the experiments we carried out previously (Pérez *et al.*, 2014, 2015; Valencia *et al.*, 2015), we found that the variability of the characteristics within a user group can be enormous. For this reason, we included the following items in the Knowledge Base: 'Assistive Technology', 'Behaviour', 'Preferences' and 'Device'.

'Behaviour' includes the adaptive techniques that are beneficial to all users who use a particular assistive technology. However, since users of the same assistive technology can also have different experience, strategies, etc, user preferences are also defined in the Knowledge Base. So users can choose which adaptation techniques they want to be applied. Moreover, they can choose added elements such as the navigation bar (up, down, etc.), font colour, sizes, etc.

In addition to preferences or assistive technology, the 'Device' was added to the ontology to define the input/output methods, the operative system of the device, the screen size, etc. The device can be gathered from the Participant Module since it can be obtained from the web browser properties. Assistive Technology instead must be set manually by the user before using the system. This also required the creation of new application rules to determine which adaptation techniques are applicable.

For instance, the next rule determines that a 'behaviour adaptation' technique is applicable to the current web page if the user is using a specific device and a concrete assistive technology.

'behaviourAdaptationHasAdaptationTechnique(?b, ?adt), isApplicable(?adt, ?d), userIsUsingDevice(?u, ?d), usesAssistiveTechnology(?u,?at), assistiveTechHasBehaviour(?at, ?b) -> adaptationTechniquesAreAppliedToUser(?adt, ?u)'

Finally, the adaptation techniques described in Section 3 were also added.

Part of the information contained in this ontology could be obtained from other ontologies, such as the Needs and Preferences part and the ICT Solutions part of the ontology presented by Koutkias *et al.* (2016). Even if we have not discarded this possibility, for this version of the system, we keep a simple set of user data and we combined all the diverse parameters that our system uses to create an adapted web page.

In order to use other ontologies, a thesaurus should be created to match the relevant elements (such as user, preferences, device model, etc.). After harvesting this information, new rules to select suitable adaptation techniques for each case may be required.

4.2.4. Adaptation module

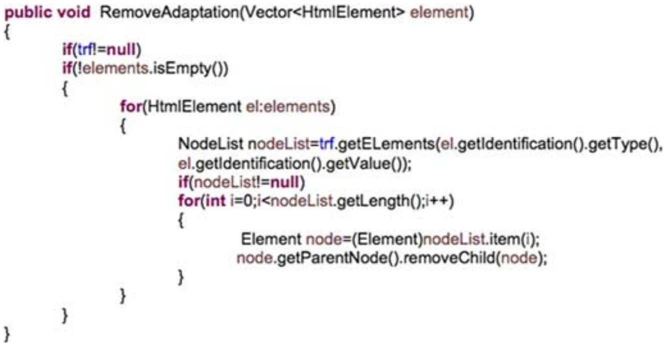
This module is responsible for performing the necessary adaptations. Its inputs are the web page and the list with the applicable adaptation techniques.

Adaptation techniques can have parameters, such as the web page elements identified by the annotation model. Some techniques do not require parameters. For example, '*provideEndTap*' requires no parameters because it is an interaction aid with no further configuration. Other techniques such as '*removeDistractors*' have those as parameter elements considered to be distractors.

After the application of all the suitable adaptation techniques the result is the adapted web page which is presented to the user.

In order to include new adaptation techniques, its Java code is stored in the adaptation module, and its definition and applicability conditions are inserted in the knowledge base, as mentioned above. Figures 8–10 show the application of a simple adaptation case to remove distractors.

When the conditions for this specific adaptation are met, the original web page (or of the associated CSS) is modified by the adaptation technique, removing inadequate code and/or adding suitable JavaScript or HTML code. For instance, the 'remove' adaptation technique receives as parameters the elements to be deleted, as it can be seen in Fig. 8. In this case, the elements 'class = publicidadGoogle' tagged as 'distractors' in Fig. 9, were removed, resulting the HMTL code in Fig. 10.



```
public void  RemoveAdaptation(Vector<HtmlElement> element)
{
        if(trf!=null)
        if(!elements.isEmpty())
        {
                for(HtmlElement el:elements)
                {
                        NodeList nodeList=trf.getELements(el.getIdentification().getType(),
                        el.getIdentification().getValue());
                        if(nodeList!=null)
                        for(int i=0;i<nodeList.getLength();i++)
                        {
                                Element node=(Element)nodeList.item(i);
                               node.getParentNode().removeChild(node);
                        }
                }
        }
}
```

Figure 8. Remove adaptation technique code.

Finally, it should be noted that the adaptation techniques are based on the roles and properties, therefore, it is possible to apply them to any annotated website. New adaptation techniques may be required to solve new sources of problems, such as the adaptation of multimedia content, or difficult texts.

5. EVALUATION

We conducted a formal evaluation, with three main objectives:

- To collect general characteristics of the users
- To test different interaction techniques
- To measure the results of applying various adaptation techniques

With this purpose in mind we divided the evaluation into two different parts: navigation tasks (Phase 1) and target acquisition tasks (Phase 2). Navigation tasks were used to compare the user interface generated by the results of the applied adaptation techniques with the original un-adapted version. Target acquisition tasks, on the other hand, were used to collect general knowledge about how participants select targets and to evaluate the different interaction techniques.

5.1. Users

Eight users with motor impairments in their upper limbs took part in the experiment. Half of them did, in fact, own tablets

```
▶ <script type="text/JavaScript">⋯</script>
▶ <script type="text/javascript">⋯</script>
  <!—Inicio Contenedor //-->
▼ <div class="publicidadGoogle">
   ▶ <div id="publicidad" class="publicidad_superior">⋯</div>
  </div>
▶ <div id="contenedor">⋯</div>
  <!—Fin contenedor-->
▶ <div>⋯</div>
▶ <script type="text/javascript">⋯</script>
```

Figure 9. Discapnet HTML code.

```
▶ <script type="text/JavaScript">⋯</script>
▶ <script type="text/javascript">⋯</script>
  <!—Inicio Contenedor //-->
▶ <div id="contenedor">⋯</div>
  <!—Fin contenedor-->
▶ <div>⋯</div>
▶ <script type="text/javascript">⋯</script>
```

Figure 10. Discapnet after removing distractors.

Table 2. Demographic data.

User	Age	Gender	Disability	Used Hand	Owns touch device?	Wheelchair
User1	41	Female	Cerebral Palsy	Right	No	Yes
User2	43	Female	Cerebral Palsy	Left	Yes (not widely used)	Yes
User3	44	Male	Cerebral Palsy	Head pointer	No	Yes
User4	55	Male	Cerebral Palsy	Left	Yes	Yes
User5	55	Female	Glutaric Aciduria Type I	Left	No	Yes
User6	55	Male	Lack of Sensibility	Right	Yes	Yes
User7	47	Male	Cerebral Palsy	Right	No	Yes
User8	60	Female	Glutaric aciduria Type I	Left	Yes (not widely used)	Yes

or smartphones, but only two of them claimed to use them regularly. Demographic data can be found in Table 2.

A Firefox Web browser with the RemoTest add-on (Valencia *et al.*, 2015), in charge of presenting stimuli and gathering interaction data from participants for posterior analyses, was installed to carry out the experimental session. In order to avoid possible side effects caused by browser characteristics, participants were encouraged to use only the website elements (not web browser menus).

5.2. Tasks and materials

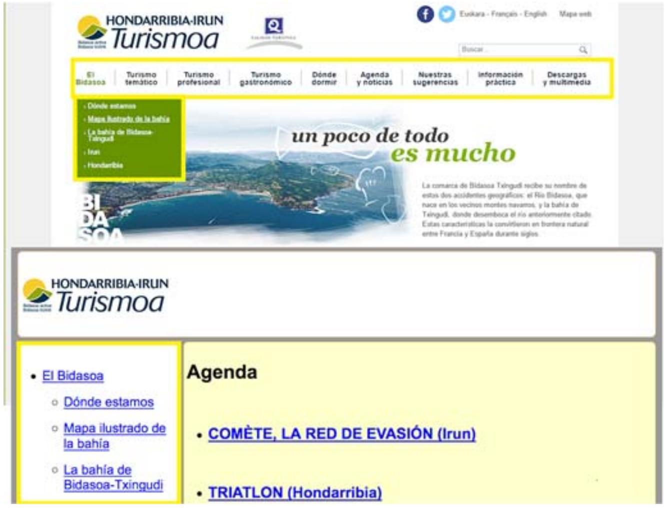
5.2.1. Phase 1*, navigation tasks*

Users were asked to perform a set of navigation tasks in two websites: Bidasoa Turismo (2016) and Discapnet (2016). Discapnet is a website specialized in providing information to people with disabilities, organizations or relatives of people with disabilities. They provide news, documentary collections, information about the rights of people with disabilities, etc. While Bidasoa Turismo provides information related to tourism, such as locations of interest, events, tourism facilities, etc.

Participant's performance under a condition (original or adapted) can be influenced by the experience acquired in the tasks performed under the previous condition. In order to avoid this learning effect, all tasks have two equivalent versions so each one could be assigned to each condition (adapted and original) indifferently. The original 'Bidasoa Turismo' website has a 9-category 'toggle' menu with more than 50 selectable items, Fig. 11, up. In the adapted version, all navigation items were displayed, increasing the page size, Fig. 11, down.

In order to contrast the adequacy of the adapted version against the toggle menu, a number of item selections were set up. Selection of the tasks was based on the scrolling requirements to reach the target (Table 3): NAV1 did not require any scroll, NAV2 required some scroll, and NAV3 was the task requiring the largest scroll, due to the target being located at the bottom of the web page.

In the original 'Discapnet' web page the size of the elements is, in general, quite small and the selectable elements are often surrounded by other elements. By contrast, the adapted version contains larger elements separated by larger spaces. As a result, this also increased the page size, thus requiring larger scrolls.



La comarca de Bidasoa Txingudi recibe su nombre de estos dos accidentes geográficos: el Río Bidasoa, que nace en los vecinos montes navarros, y la bahía de Txingudi, donde desemboca el río anteriormente citado. Estas características la convirtieron en frontera natural entre Francia y España durante siglos.

Figure 11. Bidasoa Tourism original (up) and adapted (down) with the navigation menu highlighted.

In ACT task, Fig. 12, users had to select three elements while in CA, Fig. 13, participants were required to tap on a small element that was close to other selectable elements (Table 4). In the Adapted version, these elements were larger and were more widely separated. Consequently, the page became larger in the adapted version and larger scrolling was required.

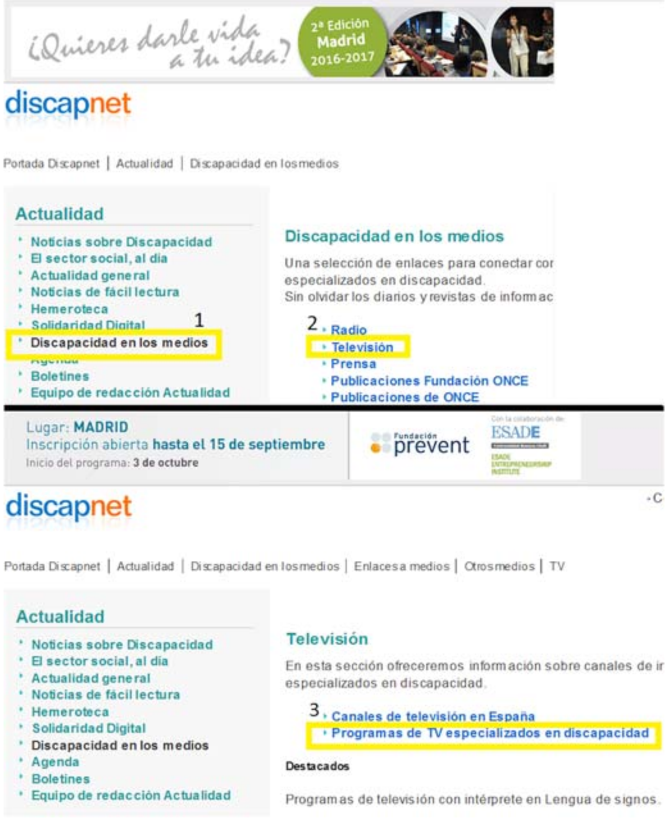
On the other hand, SD1, SD2, SD3, SD4 and SB1, SB2, SB3, SB4 tasks were search tasks that allowed participants to use the adapted and original versions more naturally (Table 5). All the search tasks in Discapnet (SD1, SD2, SD3 and SD4) were three clicks away from the homepage. In the Bidasoa Tourism website (SB1, SB2, SB3, SB4), they were two clicks away from the homepage.

5.2.2. Phase 2*, target acquisition tasks*

Target acquisition tasks were carried out to evaluate the implemented new interaction methods and to gather data about the selection of the targets (Table 6). Three web pages

Table 3. Tasks to contrast scroll in the adapted version against the toggle menu in the original.

Task	Description	Website
NAV1 and NAV1′	Target selection with no scroll in the adapted page and toggle menu in the original	Bidasoa Turism
NAV2 and NAV2′	Target selection with medium scroll in the adapted page and toggle menu in the original	Bidasoa Turism
NAV3 and NAV3′	Target selection with large scroll in the adapted page and toggle menu in the original	Bidasoa Turism



Una selección de enlaces para conectar cor
especializados en discapacidad.
Sin olvidar los diarios y revistas de informac

En esta sección ofreceremos información sobre canales de ir
especializados en discapacidad.

Programas de televisión con intérprete en Lengua de signos.

Figure 12. ACT task with the three links highlighted.

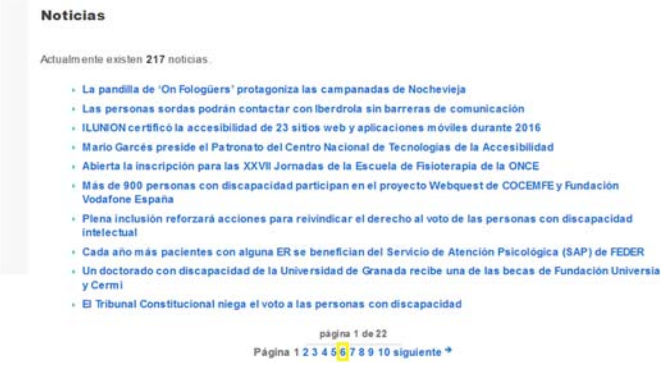
were created, each one containing nine links to be selected, with the distribution shown in Fig. 14 (TA2). The target was highlighted with a yellow background. Once the highlighted link was selected, the next link was highlighted.

In the task TA1, the link to be selected had no other links around it. In the tasks TA2 the link was bordered by two links with a standard separation (Fig. 14). The task TA3 was similar to TA2 but with a separation of 20 px between links. Four interaction methods were tested: ‘standard’, ‘end tap’, ‘steady tap’ and ‘augmented area’.

5.2.3. *Subjective measures*

In order to collect subjective data from participants, a NASA TLX questionnaire (Hart and Staveland, 1988) was used. The objective of the NASA TLX questionnaire was to analyse the adapted and original versions for each questionnaire dimension.

We also conducted a short final interview in order to ascertain which condition was their favourite and which one was more comfortable for reading and selecting elements. In addition they were also asked whether they preferred the toggle menu or the open menu.



Actualmente existen 217 noticias.

- La pandilla de ‘On Fologüers’ protagoniza las campanadas de Nochevieja
- Las personas sordas podrán contactar con Iberdrola sin barreras de comunicación
- ILUNION certificó la accesibilidad de 23 sitios web y aplicaciones móviles durante 2016
- Mario Garcés preside el Patronato del Centro Nacional de Tecnologías de la Accesibilidad
- Abierta la inscripción para las XXVII Jornadas de la Escuela de Fisioterapia de la ONCE
- Más de 900 personas con discapacidad participan en el proyecto Webquest de COCEMFE y Fundación Vodafone España
- Plena inclusión reforzará acciones para reivindicar el derecho al voto de las personas con discapacidad intelectual
- Cada año más pacientes con alguna ER se benefician del Servicio de Atención Psicológica (SAP) de FEDER
- Un doctorado con discapacidad de la Universidad de Granada recibe una de las becas de Fundación Universia y Cermi
- El Tribunal Constitucional niega el voto a las personas con discapacidad

Figure 13. CA task with the target link highlighted.

5.3. Procedure

Four participants carried out the study session in the installations of their organization, two at their home and the remaining two in the university lab. Each session lasted between one and two hours. Sessions began with the experimenter explaining the system and the experimental session.

The experimenter asked the participant where the tablet should be placed for maximum user-comfort. Different strategies were used to enable the use of the tablet depending on each participant’s needs. Two subjects used a device mount to fix the tablet to their wheelchairs (see Fig. 18). Four subjects placed the tablet on a table: one used a holder (Fig. 17), two fixed it with Velcro (Fig. 15), and a third did not use any additional help. The last two participants placed the device on a lectern (Fig. 16).

After placing the tablet, a training session was carried out to detect if additional adaptations were needed to interact with the tablet. One subject used a glove with an attached touch pen. Another user used a glove with a finger cut out and the last one used a head pointer with a touch pen.

Once the participants were ready, they were asked whether or not they wanted specific buttons to scroll the page in the interface in order to avoid the ‘swipe’ gesture. The decisions made by participants were stored as a preference in the adaptation system. Three users decided to perform direct slide gestures without assistance, while another three preferred the buttons as an alternative to the slide gesture. For the

Table 4. Task to measure the drawbacks of the added scroll against the incremented size of elements and space with surrounding elements.

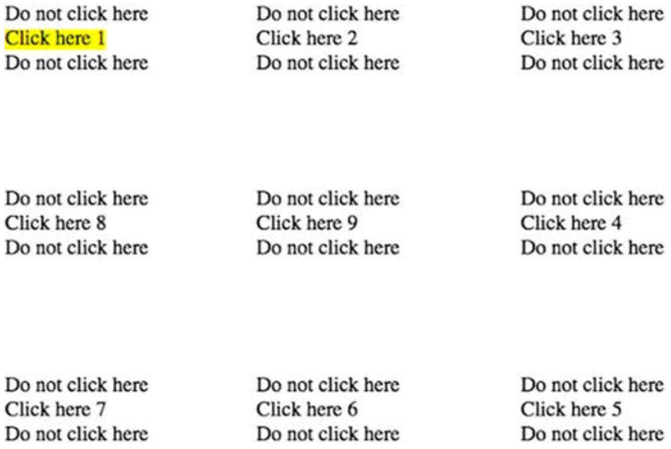
Task	Description	Website
CA and CA′	Select a small link surrounded by others at the bottom of the page	Discapnet
ACT and ACT′	Select three standard links, surrounded by others	Discapnet

Table 5. Navigation search tasks.

Task	Description	Website	Depth
SD1	Search information about the special need in education of people with disabilities	Discapnet	3
SD2	Search information about Type A flu	Discapnet	3
SD3	Search the urban transportation guide	Discapnet	3
SD4	Search information about the state of art of research in assistive technology	Discapnet	3
SB1	Search for flyovers	Bidasoa Tursim	2
SB2	Search for routes around Jaizkibel	Bidasoa Tursim	2
SB3	Search information about the ‘Faro de Higer 3ª’ Camp sites	Bidasoa Tursim	2
SB4	Search information about the ‘J.Sebastian Elkano’ youth hostel	Bidasoa Tursim	2

Table 6. Target acquisition tasks description.

Task	Description
TA1	Select the highlighted link (9 times). The link to be selected has no other links in the surroundings.
TA2	Select the highlighted link (9 times). The link to be selected is bordered by two links with a standard separation (Fig. 14)
TA3	Select the highlighted link (9 times). The link to be selected is bordered by two links with a 20px separation.



Do not click here Click here 1 Do not click here	Do not click here Click here 2 Do not click here	Do not click here Click here 3 Do not click here
Do not click here Click here 8 Do not click here	Do not click here Click here 9 Do not click here	Do not click here Click here 4 Do not click here
Do not click here Click here 7 Do not click here	Do not click here Click here 6 Do not click here	Do not click here Click here 5 Do not click here

Figure 14. Target acquisition task with target links surrounded by other selectable elements with standard separation (TA2).

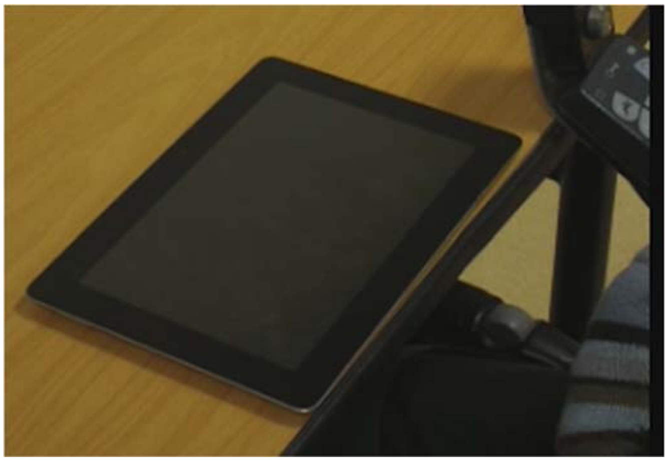


Figure 15. Tablet on the table with Velcro.

remaining two participants (User1 and User3) this setting was essential as their physical characteristics prevented them from making the ‘slide’ gesture. For this reason, the intervention of a researcher was necessary to perform the scroll in the sessions with the original version.

The experimental session was divided into three parts, Trial, Phase 1 and Phase 2. The Trial was used to enable participants to familiarize themselves with the task types and the system. Phase one was used to evaluate the design of the user interface after the application of the adaptation techniques. And finally Phase two aimed to evaluate the different interaction methods, ‘standard’, ‘end tap’, ‘steady tap’ and ‘augmented tap’.

In Phase 1 of the session, each participant carried out nine tasks under each condition, adapted and original, in two websites Discapnet (4) and Bidasoa Turismo (5). Conditions were counterbalanced between users.

For each task type (ACT and ACT′, CA and CA′, etc.) one task was assigned randomly to a condition (ACT to the adapted) and the other task was assigned to the remaining condition (ACT′ to the original). The order of tasks was

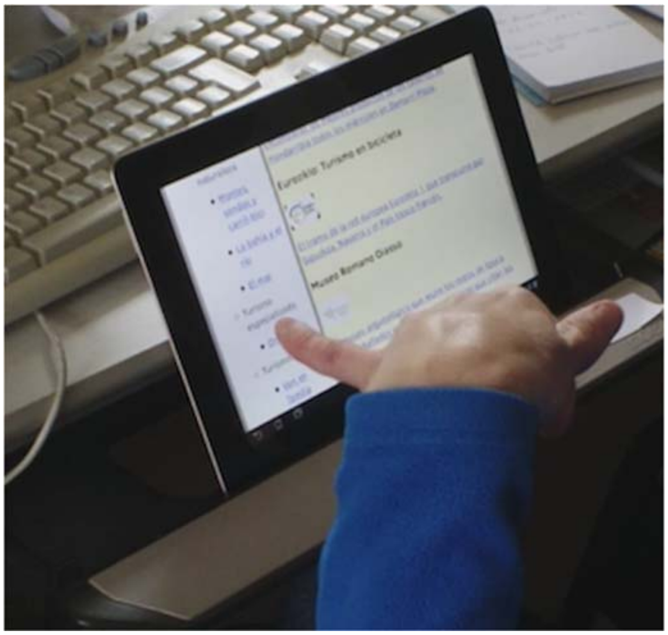


Figure 16. Tablet on a lectern.

Figure 17. Tablet on the table with a holder.

randomly assigned but the search tasks (SD1, SD2, …, SB4) were performed first. Once they completed each condition (original, adapted), participants rated it using the NASA TLX questionnaire.

Phase 2, consisted in three target acquisition tasks (TA1, TA2, TA3) that were carried out under four different interaction methods: ‘standard’, ‘end tap’, ‘steady tap’ and ‘augmented tap’. The interaction methods were counterbalanced between users and the task order was randomly selected for each user.

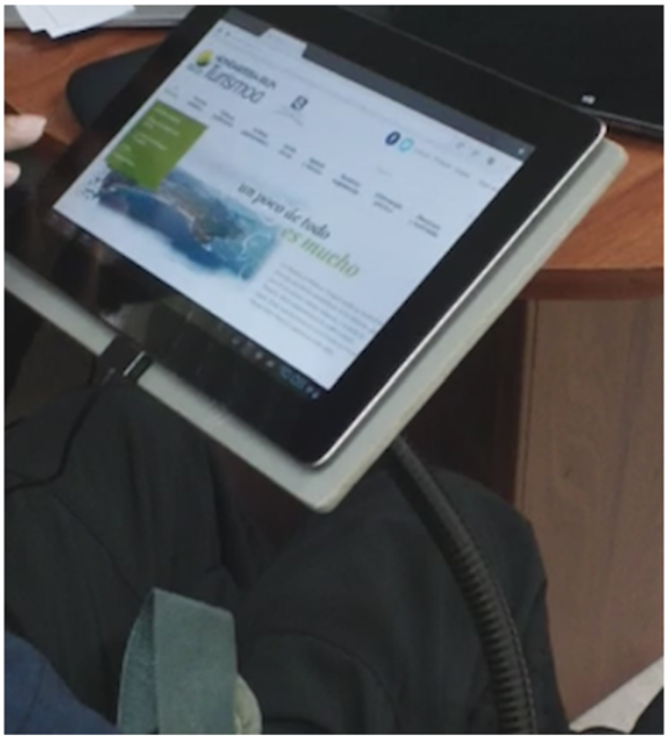


Figure 18. Tablet mounted on the wheelchair.

After finalizing the experimental session, a semi-structured interview was conducted in order to gather more information about the users’ thoughts concerning the adapted or unassisted versions.

6. RESULTS

6.1. Phase 1—navigation tasks

6.1.1. *Adaptation system performance*

In order to calculate the efficiency of the adaptation system, the time elapsed from the page request to the page load was considered from all users for the adapted version and for the original version. The average value for the adapted version was 2315.61 and 1925.67 ms for the original, a difference of 389.94 ms.

6.1.2. *Enlarge elements and increase scroll*

To analyse how much ‘enlarging the size of elements and therefore the site’ benefits or harms the users, tasks ACT, CA, NAV1, NAV2 and NAV3, were analysed. The data obtained are presented in Table 7. Data were analysed using the Student’s t-test for paired groups since the distribution of the data was normal except for CA and NAV1 tasks. In such cases, results were transformed logarithmically to have a normal distribution. In all cases the null or H0 hypothesis was ‘the adapted and original versions produce similar results’.

In the ACT task (several selections of elements) no differences were found: $t\ (7) = 0.437$, $P = 0.675$. By contrast, in

Table 7. Time needed to complete task in both conditions (adapted and original).

	ACT	CA	NAV1	NAV2	NAV3
		Adapted			
mob1	141.222	47.035	13.829	63.872	77.931
mob2	134.318	48.752	57.621	89.740	59.231
mob3	58.409	53.252	22.828	42.022	72.244
mob4	70.936	28.499	34.404	23.711	34.457
mob5	110.420	36.945	22.834	74.991	82.144
mob6	57.693	20.041	11.857	22.522	24.780
mob7	92.537	35.906	31.940	62.048	46.654
mob8	120.543	27.661	12.079	43.322	62.944
		Original			
mob1	113.285	29.644	87.696	72.818	89.030
mob2	179.573	74.760	24.907	70.850	29.875
mob3	76.017	128.293	39.488	43.429	23.940
mob4	60.255	38.332	33.866	39.731	23.435
mob5	131.105	69.609	37.552	63.170	29.981
mob6	68.955	18.448	14.961	15.871	13.583
mob7	66.066	56.716	50.999	21.533	15.268
mob8	43.735	80.440	25.950	37.816	44.810

the CA task (selecting a very small element with scroll), the differences between the adapted version and the original are very close to being significant: t (7) $= -2.2944$, $P = 0.055$. In this case, the adapted version is better than the original by an average of 24.77 s, with a confidence interval of between −0.11 and −49.42 s and an effect size of 0.81.

On the other hand, in the tasks involving a comparison of the navigation menu ('toggle menu') with the open menu, no significant differences could be found in the case with little scroll NAV1: t (7) $= -1.641$, $P = 0.145$ and an effect size of 0.58. This supposes an average enhancement of 13.5 s for the adapted version over the original.

In the case with medium scroll requirements, NAV2, no differences were found: t (7) $= 1.151$, $P = 0.287$ and an effect size of 0.40. The original was 7.13 s faster than the adapted version.

Finally, for the case with more scroll demands, NAV3, the adapted web page, showed significant differences: t (7) $= 3.22$, $P < 0.05$ and an effect size of 1.14. The original was, on average, 23.81 s faster with a confidence interval ranging from 41.30 to 63.13 s.

6.1.3. *Search tasks*

In the original condition participants were able to reach more targets, as can be seen in Table 8. Only one user (User4) finished more tasks in the adapted version. User2 did not find any and User6 found two in each version. The rest found more targets in the original, the most prominent being User7 who found three in the original and none in the adapted version.

Table 8. Number of tasks completed in search tasks in both conditions.

	Adapted	Original
mob1	2	3
mob2	0	0
mob3	0	1
mob4	2	1
mob5	0	1
mob6	2	2
mob7	0	3
mob8	1	3

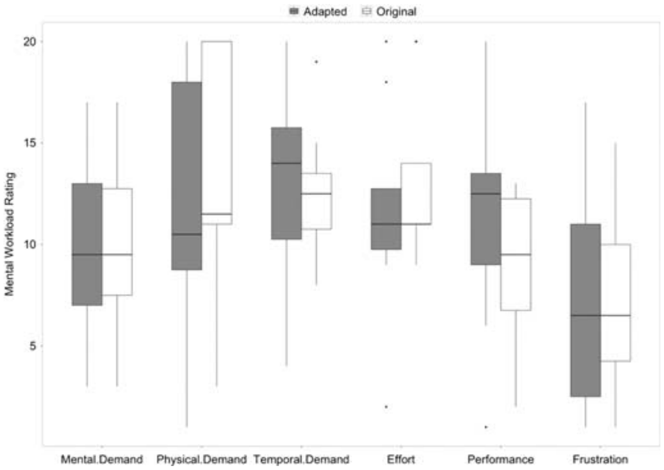


Figure 19. Boxplot for each NASA TLX questionnarie dimension.

6.1.4. *NASA TLX questionnaire results*

Each of the dimensions of the NASA TLX questionnaire was analysed with the Wilcoxon test. The resulting dimension distribution can be seen in Fig. 19.

Unexpectedly, no significant differences were found for Mental Demand, even if in the adapted version both sites had the same structure ($W = 9.5$, $Z = -0\,428$, $P = 0.688$). Neither were any differences found for the Effort dimension ($W = 0$, $Z = -1\,720$, $P = 0.25$). By contrast, significant differences were found in Physical Demand ($W = 0$, $Z = -2.40$, $P < 0.05$, effect size $= 0.849$) in favour of the adapted version. Regarding Temporary Demand ($W = 6.5$, $Z = 0.835$, $P = 0.625$) and Performance ($W = 22$, $Z = 0.566$, $P = 0.656$), users tended to value the original page higher, although not significantly. Finally, Frustration Level ($W = 12.4$, $Z = 0.567$, $P = 0.625$) was very similar for both types of pages.

6.2. Phase 2—target acquisition tasks

6.2.1. *How users select targets in a touch screen*

The target acquisition tasks (TA1, TA2, TA3) allowed the analysis of the different interaction methods: 'standard', 'augmented', 'end' and 'steady'. How participants select the targets was also analysed with the date obtained from the 'standard' method of interaction. We collected average distances from the centre of the target to the points where the finger touched the screen (TD) and left the screen (TU). The distance (D) travelled by the finger while selecting was also measured and its relation to the optimal distance (CI). In addition, the number of times (NF) that each user touched the screen with more than one finger was counted.

Table 9 presents the results gathered from the standard method of interaction. Most users did not move their fingers substantially during the selection except User8 who moved their finger 10.8 mm on average. Other users, such as User2, User5 and User7, also moved their fingers during target selection 4.90, 3.76 and 3.65 mm, respectively.

User8 had the largest CI, 2.07, followed by User7 (1.88), User2 (1.50) and User5 (1.27). This indicates that their fingers travelled longer than optimal distances indicating that they might have precision or control problems.

On the other hand, User1, User2 and User3 located their fingers quite far from the centre of the object 31.39, 29.21 and 31.39 mm, respectively, indicating difficulties in making the right selection.

With regard to the number of times they touched the screen with more than one finger, User2 did this eleven times. Evidently, touching the screen with more than one finger hindered the user from making an accurate target selection.

The three different scenarios discussed above were considered to assess the four different methods of interaction. Since data were not normal, it was analysed with the non-parametric Friedman test. In all scenarios the null hypothesis H0 was 'there are no differences between alternative methods and the standard one'.

6.2.2. TA1: *target selection with nothing around*

The Friedman's test found no significant differences between the methods of interaction, χ^2 (3) = 1.819, $P = 0.610$. Although the differences were not significant, the 'augmented' method achieved, on average, the lowest value (3516.78 ms), followed by 'end' (3783.77 ms), standard (4329.38 ms) and finally 'steady' (5055.23 ms). As can be seen in Fig. 20, the data are more compact for 'augmented'.

Table 9. Users' characteristics from target acquisition tasks with standard interaction.

	TD	TU	D	CI	CTU
mob1	32.14	32.91	0.62	1.00	0
mob2	29.21	28.56	4.90	1.50	11
mob3	31.39	31.08	0.48	1.00	0
mob4	3.51	3.51	0	1	0
mob5	13.95	12.84	3.76	1.27	0
mob6	5.28	5.28	0	1	0
mob7	15.36	15.43	3.65	1.88	0
mob8	18.54	19.02	10.80	2.07	0

For all the users, except for User6, at least one of the alternative methods of interaction produced a better average value. In some cases (User7, User4, User3, User1, User5), the difference was small: less than a second. Other users obtained higher differences on average: User2 obtained 3 s and User8 7 s.

6.2.3. TA2: *target selection with two bordering links with standard separation*

In this scenario significant differences were found: χ^2 (3) = 41,732, $P < 0.01$. A Mann–Whitney test with a Bonferroni correction *post hoc* test, showed differences between standard and 'augmented' ($P < 0.01$), but not with others (standard-end and standard-steady, $P = 1$).

The 'augmented' method, which, having produced good results in the previous case, was the worst this time. Having to frequently disambiguate between probable targets significantly increases the time required to select an item. In general, 'end' (3930.08 ms) produced the best value on average, followed by 'steady' (4202.85 ms), 'standard' (4297.57 ms) and 'augmented' (10 597.92 ms) as shown in Fig. 21.

User1, User4, User5 and User6 obtained better values with the 'standard' interaction method. 'End' is similar to the 'standard' for the participants User3, User4 and User6 (<300 ms). The subject User2 obtained an average difference of 6 s with 'steady' and 3 s with the 'end'. User7 obtained a difference of about 2 s with 'end' and 'steady'. Finally, User8 obtained a difference of almost 5 s with 'steady' and nearly 3 s with 'end'.

6.2.4. TA3: *target selection with two bordering links with a 20 px separation*

In this case, the Friedman test found significant differences: χ^2 (3) = 48,337, $P < 0.01$. The Mann–Whitney post hoc

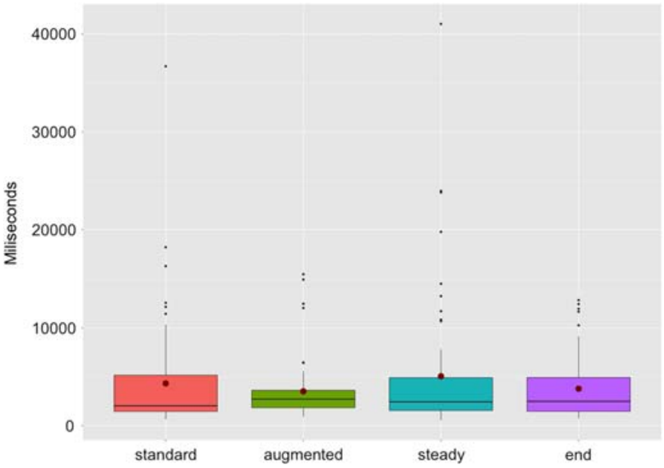


Figure 20. User selection time boxplots, by interaction method (links not surrounded by other selectable items).

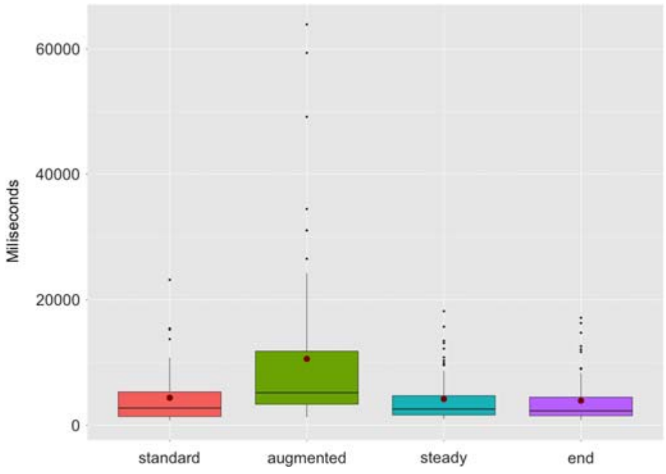


Figure 21. User selection time boxplots, by interaction method (links bordered by other selectable items).

analysis with Bonferroni correction, showed differences between ‘standard’–‘augmented’ ($P < 0.05$), and ‘standard’–‘steady’ ($P < 0.05$). In both cases, the differences were in favour of the standard interaction method. Overall ‘end’ produced better average results (3192.83 ms) closely followed by ‘standard’ (3232.52 ms). Slightly further behind were ‘steady’ (4135.98 ms) and ‘augmented’ (8105.34 ms) as can be appreciated in Fig. 22.

On average, the ‘standard’ was better for User1, User3, User4, User7 and User8. However, ‘end’ produced similar values to the ‘standard’, except for User8. User6 obtained a minimal difference with ‘end’. User5 reduced the time by 1 s with ‘steady’ while User2 reduced the time by almost half with ‘end’.

6.2.5. *Was any interaction method helpful for any participant?*

To find out whether, in any of the cases, the alternative methods were of any help, we analysed the users with the highest CI (User2, User7 and User8).

Firstly, we analysed User2, for whom significant differences were found in TA2: χ^2 (3) $= 14.6$, $P < 0.01$, although the post hoc test could not clarify which pairs were implied (‘standard’–‘augment’ 1, ‘standard’–‘steady’ 0.50, ‘standard’–‘end’ 1). Although for TA1 no significance was obtained it was quite close: χ^2 (3) $= 6.6$, $P = 0.086$. The same result was obtained with the post hoc test.

For User7, no differences were found in TA1 and TA3 but there were differences in TA2: χ^2 (3) $=$ 13,133, $P < 0.01$ and in the post hoc values: ‘standard’–‘augmented’ 1, ‘standard’–‘steady’ 0.291, ‘standard’–‘end’ 0.085. Although not significantly, ‘end’ is very near to differentiating (0.085). Therefore, it would appear that this user could benefit from ‘end’ when the selected target is surrounded by other targets.

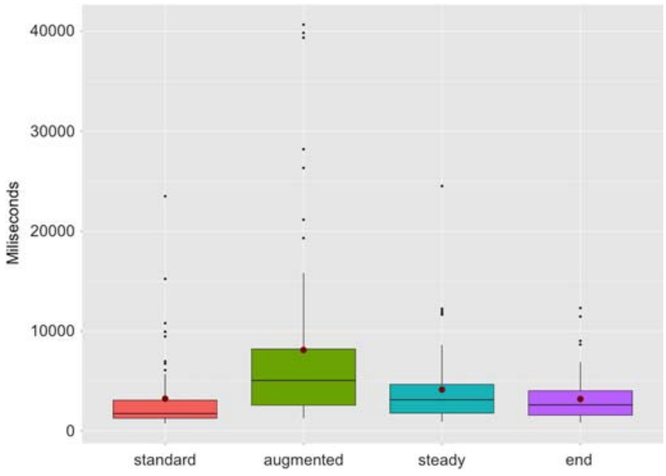


Figure 22. User selection time boxplots, by interaction method (links bordered with 20 px separation).

Finally, User8 obtained significant results in all three cases: χ^2 (3) $= 13.93$, $P < 0.01$, χ^2 (3) $= 17.4$, $P < 0.01$ and χ^2 (3) $= 13.4$, $P < 0.01$. The post hoc test could not find differences between the groups in TA1 (‘standard’–‘augmented’ $P = 0.767$, ‘standard’–‘steady’ $P = 0.291$ and ‘standard’–‘end’ $P = 1$). In TA2 the results were better for ‘steady’ (‘standard’–‘augmented’ $P = 1$, ‘standard’–‘steady’ $P = 0.0488$, ‘standard’–‘end’ $P = 0.3249$). In TA3, the differences were found only for ‘augment’ worsening the time needed (‘standard’–‘augmented’ $P = 0.012$, ‘standard’–‘steady’ $P = 1$, ‘standard’–end’ $P = 0.182$).

6.3. Interview

Following the sessions, a final interview was carried out to obtain the thoughts and preferences of the users on both the adapted and the original websites. The following questions were asked in the interviews:

- Overall which is your preferred interface (Adapted, Original)?
- Which one is more comfortable for reading and selecting links (Adapted, Original)?
- Which do you prefer, having more space between links and an increased page size or having less space and a reduced page size?
- Which do you prefer, an open menu or a toggle menu?
- Do you think it is useful to maintain the structure of pages within websites?
- Can you perform the Zoom gesture?
- Can you perform the Slide gesture?

All but two participants (user6 and user8) preferred the adapted version to the original one, both from an overall point of view and specifically for reading or selecting links. Six participants preferred to have more space between links, one less space (user2) and the last one did not answer.

With regard to the open menu vs. toggle menu, five participants selected the toggle menu while the other three (user2, user5, user7) preferred the open menu. All but one thought that maintaining the same structure across websites could be useful. The remaining participant was indifferent once they had become accustomed to the different structure of the website.

With regard to the questions about the Zoom or the Slide gestures, only one participant (user6) was able to perform these without significant problems. The slide gesture was easier for most users although two participants (user1, user3) were not able to do it.

7. DISCUSSION

As far as design issues are concerned, it seems clear that having to perform a considerable amount of scrolling increased the time required to perform the task (NAV3). However, the larger size of the links and the space between elements added in the adapted page seems to have been helpful (NAV1). The absence of significant differences in NAV2 is quite promising, as performing the task in the adapted page entailed a certain amount of scrolling. On the other hand, when the links are very small and they are surrounded (CA) better results are obtained with the adapted page, despite the need to do more scrolling.

However, it should be pointed out that faster is not always better (a vision focused on productivity or business). Users do not always prefer to be faster, as indeed they reported for our study: six of eight preferred the adapted page. Comfort, reduction in the number of mistakes or easier item selection can be factors that lead to forming a preference for the adapted pages, even though task performance times may be longer.

The results in the search tasks might be explained because participants were probably already used to the structure of the sites. Another issue would be the use of the breadcrumbs as a method for identifying the page or section in the adapted page. Most of the users who took part in the study do not usually use—and are unfamiliar with—breadcrumbs. Therefore, a possible improvement would be the use of colours for the sections. Moreover, the information about the section in which the users find themselves should be more evident (and not based on breadcrumbs).

From the NASA TLX questionnaire it can be seen that adapted pages generated less physical demand, which is very important for people with motor disabilities. Results (although not significant) of the adapted pages in performance, frustration or time demand, seem to be explained by the probable relation with the number of completed tasks in each condition (adapted and original).

Regarding the target acquisition tasks, interestingly most users needed, on average, more time for the task with only one link (TA1) than for the other tasks, using the 'standard' interaction. The explanation could be that when the links are at the edges of the screen unintentional pressing or interaction with buttons on the navigation bar, back button, the watch, etc. can happen. On the other hand, in TA3 the best results were obtained in contrast to TA2 and TA1 by the different methods of interaction except 'steady'. This highlights the importance of active elements being maintained at a minimum distance from each other.

The 'augmented' technique applied to targets which were not surrounded appears to provide some help to many users, though not significantly. For other cases, having to disambiguate increases the target selection time significantly, making it unsuitable for surrounded interactive elements.

Some users can gain an advantage from alternative methods of interaction under certain conditions. Examples of this are the subjects User2 and User8, in the cases TA1 and TA2, with the steady method, or User7, with 'end', in TA2. In order to help other users, such as User1 and User3, it would be necessary to detect their pattern to select elements in order to preview the objective they want to click (Montague *et al.*, 2012; Mott *et al.*, 2016). Remember that, even if they do not drag their fingers for selection, they set them down slightly away from the target (>3 cm).

Finally, from the results of the users' feedback regarding the menus, it is important to provide a customization option for the type of menu ('open' or 'toggle'). Although the use of these types of menus for people with physical disabilities is not recommended, five users preferred it.

8. CONCLUSIONS

The evaluation carried out showed that the implemented transcoding system is able to adapt websites to touch screen mobile devices used by people with motor impairments. As a result, most users prefer transcoded pages, although several improvements in the user interface and in the interaction methods are required. Some of the required improvements are discussed below.

8.1. User interface

Regarding the user interface, more customization features are needed. Such as, for example, letting the users set their preferred font size or the minimum size of interaction elements.

The final interview showed that a number of users preferred a 'toggle' over the 'open' menu. This choice can be also provided by the system as a user preference. The provision of these options would allow the page size to be adjusted adequately—and therefore the need for scrolling—to the user requirements. This, in consequence, would help to reduce the time needed to accomplish their tasks.

Finally, the importance of providing buttons for scrolling was highlighted. While performing the 'slide' gesture is possible for most users, for some other users it is a very difficult—or impossible—gesture. The simple act of providing buttons for scrolling can make the difference between being able to surf the web or not.

8.2. Interaction methods

Due to the high variability of the characteristics and needs of users with motor disabilities, finding an optimal alternative method of interaction for everyone was not possible. However, some methods work well for specific people under particular circumstances. For instance, participants whose fingers move without control during the selection of targets can benefit from ‘end tap’ or ‘steady tap’ interaction methods.

The lack of more universal interaction methods could be resolved by a more thorough longitudinal study that would enable us to determine when—and for whom—one interaction method is better than another. This knowledge can be used to provide a path towards dynamically adaptive interaction. For instance, in an adaptive system, ‘augmented tap’ would be applied when a selectable element is alone and ‘steady tap’ or ‘end tap’ when the element is surrounded by other elements.

Nevertheless, it should not be overlooked that interaction methods must be changed with caution. Changes in the interaction techniques should not interfere with consolidated gestures, such as ‘slide’. Therefore, in addition to testing interaction methods with target selection tasks, these should also be evaluated while surfing the web. This can help to determine how useful the alternative interaction method really is.

ACKNOWLEDGEMENT

We would like to thank all the participants that took part in the study.

FUNDING

This research work was developed within the project eGovernability, funded by the Spanish Government, Ministry of Economy, Industry and Competitiveness (MINECO), and the European Regional Development Fund (ERDF), under grant (TIM2014-52665-C2-1-R). J.E.P. holds a PhD Scholarship from the University of the Basque Country (UPV/EHU). Some of the authors are members of the EGOKITUZ/ADIAN research team, supported by the Basque Government, Department of Education, Universities and Research under grant (IT980-16).

REFERENCES

Abram’s, M., Phanouriou, C., Batongbacal, A.L., Williams, S.M. and Shuster, J.E. (1999) UIML: an appliance-independent XML user interface language. Comput. Netw., 31, 1695–1708.

Akpınar, E. and Yeşilada, Y. (2015) Old habits die hard!: eye tracking based experiential transcoding: a study with mobile users. In Proc. 12th Web for all Conf. (12 pages). ACM

Asakawa, C. (2005) What’s the web like if you can’t see it? In Proc. 2005 Int. Cross-Disciplinary Workshop on Web Accessibility (W4A) (pp. 1–8)

Asakawa, C. and Takagi, H. (2008) Transcoding. In Web Accessibility. pp. 231–260. Springer, London.

Belatar, M. and Poirier, F. (2008) Text entry for mobile devices and users with severe motor impairments: handiglyph, a primitive shapes based onscreen keyboard. In Proc. 10th Int. ACM SIGACCESS Conf. Computers and accessibility, pp. 209–216.

Bidasoa Turismo (2016) http://www.bidasoaturismo.com/

Discapnet (2016) http://www.discapnet.es/Castellano/Paginas/default.aspx

Findlater, L., Jansen, A., Shinohara, K., Dixon, M., Kamb, P., Rakita, J. and Wobbrock, J.O. (2010) Enhanced area cursors: reducing fine pointing demands for people with motor impairments. In Proc. 23nd annual ACM symposium on User interface software and technology, pp. 153–162.

Gajos, K. and Weld, D.S. (2004) SUPPLE: automatically generating user interfaces. In Proc. 9th Int. Conf. Intelligent user interfaces, pp. 93–100.

Ghiani, G., Manca, M., Paternò, F. and Porta, C. (2014) Beyond responsive design: context-dependent multimodal augmentation of web applications. In Int. Conf. Mobile Web and Information Systems, pp. 71–85.

Greasmonkey (2016) https://addons.mozilla.org/es/firefox/addon/greasemonkey/

Grossman, T. and Balakrishnan, R. (2005) The bubble cursor: enhancing target acquisition by dynamic resizing of the cursor’s activation area. In Proc. SIGCHI Conf. Human factors in computing systems, pp. 281–290.

Gruber, T.R. (1993) A translation approach to portable ontology specifications. Knowl. Acquis., 5, 199–220.

Guerreiro, Y., Nicolau, H., Jorge, J. and Gonçalves., D. (2010) Towards accessible touch interfaces. In Proc. 12th Int. ACM SIGACCESS Conf. Computers and accessibility (ASSETS ‘10). pp. 19–26, ACM, New York, NY, USA.

Harper, S. and Bechhofer, S. (2007) SADIe: structural semantics for accessibility and device independence. ACM Trans. Comput. Hum. Interact., 14, 10 pages.

Hart, S.G. and Staveland, L.E. (1988) Development of NASA-TLX (Task Load Index): results of empirical and theoretical research. Adv. Psychol., 52, 139–183.

IMS ACCLIP (2016) http://wiki.cetis.ac.uk/ACCLIP_Briefing

Ivory, M.Y., Mankoff, J. and Le, A. (2003) Using automated tools to improve web site usage by users with diverse abilities. IT Soc., 1, 195–236.

Kane, S.K., Jayant, C., Wobbrock, J.O. and Ladner, R.E. (2009) Freedom to roam: a study of mobile device adoption and accessibility for people with visual and motor disabilities. In Proc. 11th

Int. ACM SIGACCESS Conf. Computers and accessibility, pp. 115–122.

Knutov, E., De Bra, P. and Pechenizkiy, M. (2009) AH 12 years later: a comprehensive survey of adaptive hypermedia methods and techniques. New Rev Hypermedia Multimed., 5, pp. 5–38.

Koutkias, V., Kaklanis, N., Votis, K., Tzovaras, D. and Maglaveras, N. (2016) An integrated semantic framework supporting universal accessibility to ICT. Univ. Access Inform. Soc., 15, 49–62. 0.

Li, L. and Gajos, K.Z. (2014) Adaptive click-and-cross: adapting to both abilities and task improves performance of users with impaired dexterity. In Proc. 19th Int. Conf. Intelligent User Interfaces, pp. 299–304.

Limbourg, Q., Vanderdonckt, J., Michotte, B., Bouillon, L. and López-Jaquero, V. (2004) USIXML: a language supporting multi-path development of user interfaces. EHCI/DS-VIS, 3425, 200–220.

Mirri, S., Salomoni, P., Prandi, C. and Muratori, L.A. (2012) GAPforAPE: an augmented browsing system to improve Web 2.0 accessibility. New Rev Hypermedia Multimed., 18, pp. 205–229.

Mobile Accessibility (2016) https://www.w3.org/WAI/mobile/

Mobile Web Application Best Practices (2016) http://www.w3.org/TR/mwabp/

Mobile Web Best Practices (2016) https://www.w3.org/TR/mobile-bp/

Montague, K., Hanson, V.L. and Cobley, A. (2012) Designing for individuals: usable touch-screen interaction through shared user models. In Proc. 14th Int. ACM SIGACCESS Conf. Computers and accessibility, pp. 151–158.

Mott, M.E., Vatavu, R.D., Kane, S.K. and Wobbrock, J.O. (2016) Smart Touch: Improving Touch Accuracy for People with Motor Impairments with Template Matching. In Proc. 2016 CHI Conf. Human Factors in Computing Systems, pp. 1934–1946.

Nicolau, H., Guerreiro, T., Jorge, J. and Gonçalves, D. (2014) Mobile touchscreen user interfaces: bridging the gap between motor-impaired and able-bodied users. Univ. Access Inform. Soc., 13, 303–313.

OWL (2016) https://www.w3.org/TR/owl-features/

Paterno, F., Santoro, C. and Spano, L.D. (2009) MARIA: a universal, declarative, multiple abstraction-level language for service-oriented applications in ubiquitous environments. ACM Trans. Comput. Hum. Interact., 16, 19 pp.

Pérez, J.E., Arrue, M., Valencia, X. and Moreno, L. (2014) Exploratory study of web navigation strategies for users with physical disabilities. In Proc. 11th Web for All Conf. pp. 4

Pérez, J.E., Valencia, X., Arrue, M. and Abascal, J. (2015) Depicting the keypad mouse interface: exploring pointing behaviors of three input devices. In Proc. 17th Int. ACM SIGACCESS Conf. Computers & Accessibility, pp. 413–414.

Protégé (2016) http://protege.stanford.edu

Richards, J.T. and Hanson, V.L. (2004) Web accessibility: a broader view. In Proc. 13th Int. Conf. World Wide Web, pp. 72–79.

SWRL (2016) https://www.w3.org/Submission/SWRL/

Takagi, H. and Asakawa, C. (2000) Transcoding proxy for nonvisual web access. In Proc. 4th Int. ACM Conf. Assistive technologies, pp. 164–171.

Takagi, H., Asakawa, C., Fukuda, K. and Maeda, J. (2002) Site-wide annotation: reconstructing existing pages to be accessible. In Proc. 5th Int. ACM Conf. Assistive technologies, (pp. 81–88).

Trewin, S., Swart, C. and Pettick, D. (2013) Physical accessibility of touchscreen smartphones. In Proc. 15th Int. ACM SIGACCESS Conf. Computers and Accessibility (ASSETS '13). ACM, New York, NY, USA, Article 19, (8 pages).

Trewin, S., Keates, S. and Moffatt, K. (2006) Developing steady clicks: a method of cursor assistance for people with motor impairments. In Proc. 8th Int. ACM SIGACCESS Conf. Computers and accessibility, pp. 26–33.

Valencia, X., Arrue, M., Pérez, J.E. and Abascal, J. (2013) User individuality management in websites based on WAI-ARIA annotations and ontologies. In Proc. 10th Int. Cross-Disciplinary Conf. Web Accessibility, pp. 10.

Valencia, X., Pérez, J.E., Muñoz, U., Arrue, M. and Abascal, J. (2015) Assisted interaction data analysis of web-based user studies. Hum. Comput. Interact., LNCS 9296, 1–19.

WAI-ARIA (2016) https://www.w3.org/TR/wai-aria/

WCAG 2.0 (2016) https://www.w3.org/TR/WCAG20/

Wobbrock, J.O., Fogarty, J., Liu, S.Y.S., Kimuro, S. and Harada, S. (2009) The angle mouse: target-agnostic dynamic gain adjustment based on angular deviation. In Proc. SIGCHI Conf. Human Factors in Computing Systems, pp. 1401–1410.

Wobbrock, J.O., Myers, B.A. and Kembel, J.A. (2003) EdgeWrite: a stylus-based text entry method designed for high accuracy and stability of motion. In Proc. 16th annual ACM symposium on User interface software and technology, pp. 61–70.

XPATH (2016) https://www.w3.org/TR/xpath/

Yesilada, Y., Brajnik, G. and Harper, S. (2011) Barriers common to mobile and disabled web users. Interact. Comput., 23, 525–542.