Back Navigation Shortcuts for Screen Reader Users

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ABSTRACT

When screen reader users need to back track pages to re-find previously visited content, they are forced to listen to some portion of each unwanted page to recognize it. This makes aural back navigation inefficient, especially on large websites. To address this problem, we introduce topic- and list-based back: two navigation strategies that provide back browsing shortcuts by leveraging the conceptual structure of content-rich websites. Both are manifested in Webtime, an accessible website on the history of the Web. A controlled study (N=10) conducted at the Indiana School for the Blind and Visually Impaired compared topic- and list-based back to traditional back mechanisms while participants completed fact-finding tasks. Topic- and list-based back significantly decreased time-on-task and number of backtracked pages; the navigation shortcuts were also associated with positive improvements in perceived cognitive effort and navigation experience. The proposed strategies can operate as a supplement to current back mechanisms in information-rich websites.

Categories and Subject Descriptors

H.5.2 [**Information Interfaces and Presentation**]: User Interfaces – *Interaction styles;* K.4.2 [Computers and Society]: Social Issues – *Assistive technologies for person with disabilities.*

General Terms: Measurement, Performance, Design, Reliability, Experimentation, Human Factors.

Keywords: Information architecture, back navigation, screen reader users, assistive technology.

1. INTRODUCTION

According to the American Printing House for the Blind, in the year 2010, there were about 59,341 legally blind children – up to 21 years old – in the U.S. [36]. Due to the increasingly pervasive role of web technology and the need for blind users to adequately navigate the web, significant research has contributed novel ways to improve web access for screen reader users [5, 28, 31]. Accessing the content, however, is a necessary yet not sufficient condition for the usability of a website. By recognizing that websites that are technically accessible still pose fundamental problems to screen reader users [19], there is still important research to be done to ensure *usable accessibility*, so that all users can use the web efficiently and effectively [12].

In particular, screen readers have a linear reading strategy that processes each page from *top-left* to *bottom-right*, making it difficult, boring and frustrating to keep skipping unnecessary information and wait for the relevant content or link to be read. This reading strategy is in contrast with the visual scanning of a complex page, whereby users can easily get orientation cues, as well as master the structure and flow of a page at a glance. This basic problem is exacerbated in the context of back navigation with screen readers. In fact, when screen reader users decide to go back to look for some specific information or regain orientation, they would need to listen to and recognize at least a portion of each intermediate page before they get to the desired content. At each page, users must aurally recover orientation to realize what the page is about, decide whether or not that page is the one they were looking for, and possibly repeat this process for every step in the history. Whereas sighted users can very quickly master a long series of backtracked pages by visual scanning, backtracking with screen readers is a long and inefficient process.

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To address this challenge, this paper makes three contributions:

- Models topic- and list-based back, two advanced back navigation strategies which provide back browsing shortcuts to screen reader users by leveraging the conceptual structure of content-rich websites;
- Reifies these strategies in Webtime, an accessible web system prototype targeted to blind and low-vision high school students on the history of the Web;
- Presents a controlled study with 10 blind high school students at the Indiana School for the Blind and Visually Impaired (ISBVI)[1], who tested the usability of topic- and list-based back with Webtime.

This research is framed within a larger NSF-funded project aimed at investigating design strategies to *navigate the aural web*. Our work is compounded by a parallel study that we recently published [35], in which the same navigation shortcuts increased navigation efficiency for sighted users while browsing the web on the go with their mobile devices. Our rationale is that the same fundamental strategies can benefit both sighted and screen reader users while *aurally* navigating a website.

2. RELATED WORK

Our work relates to research efforts in accessibility with screen readers, aural browsers, back navigation and conceptual modeling.

2.1 Accessibility with Screen Readers

Many studies have confirmed that, although the adherence to the Web Accessibility Initiatives (WAI) guidelines helps ensure *technical readability* of the web page, it does not at all ensure that a website is actually accessible to blind users [1, 7]. Petrie et al. [27] demonstrated that many websites, which are officially fully compliant with existing W3C guidelines [33], are not actually accessible. Blind users still have enormous difficulties in using them, especially while navigating complex information architectures. The body of work [17, 29] on the limits of screen readers highlights issues related to *usable accessibility*. *Sequential browsing* – especially for long lists of items - is the most time consuming strategy for blind users [5]. For example, the Google News home page contains more than 350 links, which can be very frustrating for screen reader users [19]. To enable designers to easily spot the pages which are not usable for blind users, Takagi et al. [28] introduce advanced accessibility checkers. This is

[1] http://www.isbvik12.org/

another indicator that screen reader users still experience frustration when browsing the web. Our research highlights the need to address *usable accessibility* beyond *technical readability*, and thus to tackle profound issues of aural navigation design, besides improving the readability of each single page.

2.2 Advanced Aural Browsers

Novel aural browsers have been developed to overcome some of the known limitations of screen readers and provide advanced accessibility support for visually impaired users browsing the web [3, 6, 14, 16, 29]. Among the most well-known aural browsers we include HearSay [4], CSurf [21], SADIe (Structural Semantics for Accessibility and Device Independence) [20], and aiBrowser [23].

HearSay is a non-visual web browser that provides additional features with respect to existing screen readers, including: (i) the ability to "track" the changes on webpages which are frequently updated as a consequence of user interaction (e.g. search pages); (ii) the ability to identify the language of the content and select the suitable text-to-speech engine to read it aloud; (iii) finally, as an advanced feature, HearSay allows users to change the labels of the links in the page and share the user-generated labels with other users [4].

SADIe is a proxy-based tool for the visual-to-aural transcoding of an entire website. It relies on ontological annotations of the Cascading Style Sheets (CSS) to apply accurate and scalable transcoding algorithms. SADIe accomplishes this through three operations: defluff, which involves removing elements that provide little or no information to the page; reorder, which involves reordering the page so that *important areas* of content appear near the top of the page (to be read first); and menu, which displays the website menu at the bottom of the page [20].

The state of the art of aural browsers indicates that important results have been achieved in the effort to overcome the limits of screen readers for auralizing websites. Our work fits into this line of work to advance the screen reader user experience by focusing on back navigation. Specifically, we explore navigation strategies for aural applications which go beyond an intelligent adaptation and optimization of the visual websites for the aural channel. Much work has yet to be done in exploring fundamentally new ways to enable blind users to more easily master – during interaction – the complexity of the information architecture of the application (beyond the level of an individual page).

2.3 Back Navigation

Over the last fifteen years, there have been several studies that – although not directly related to screen reader users – investigated the pervasive role and importance of back navigation. In 1995, Catledge and Pitkow analyzed log files for three weeks and found that back navigation accounts for 41% of all web interaction activities [8] and the recurrence rate of page visits was 61% [30]. In 2001, McKenzie and Cockburn analyzed log files for four months and found that page re-visitation accounts for 81% of the total set of navigation actions [24]. Exploiting the characteristics of web navigation history, Milic-Frayling et al. [26] considerably improved the back navigation experience by visualizing the types and structures of users' navigation history. With *SmartBack*, users could visualize the dynamic *hubs* of in-depth web browsing and use these landmarks to re-find orientation. Similarly, Cui et al. [11] suggest that *navigation history* should be designed by arranging the key content that users have visited and skip *less meaningful pages*. Whereas these strategies might generate limited gain in efficiency for visual web browsing, the idea to use higher level abstractions to improve backtracking design has a great potential to solve the current inefficiency of aural back browsing.

2.4 Web Navigation Modeling

High-level, structured design models have been proposed for designing the features of an interactive application at a proper level of abstraction. Especially in the field of hypermedia, web and ubiquitous computing, rigorous concepts, process guides, as well as formal and semi-formal notations have been developed to master the complexity of large, information-intensive systems. Examples include IDM [2], WebML [9], and UMLWAE [10], just to name a few. The focus of this research tradition is on modeling the conceptual structure of the information architecture and navigation and representing their implications for the design of the user interface. This rich body of knowledge, however, always operated under the assumption that visualization was the only interaction paradigm for web applications. As a consequence, the research on defining conceptual design primitives for aural navigation by rethinking, adapting or creatively re-using existing models remains a largely unexplored area to date. Our work leverages this tradition to introduce navigation shortcuts for screen reader users that leverages the underlying conceptual structure of large web applications.

3. BACKTRACKING SHORTCUTS

3.1 Topic-based Back Navigation

Current large web applications model every navigation unit as a *page* or node. In large, information-intensive websites, however, content pages are typically designed and *held* together to represent a coherent *information entity*, or *topic* [2]. For example, in a website for academic department, a main topic is *academic program*. A topic may consist of a number of pages, for example, the pages that provide a basic introduction to the program, the page for the admission instructions, and the page with the study plan or curriculum. Users navigate pages, but while navigating pages, they traverse topics.

Envision a scenario in which screen reader users are moving from the *description* page ❶ of Ph.D. program in Biology (see Figure 1 left) to the admission ❷ and the curriculum information ❸. From there, they navigate to the Ph.D. program's faculty (Professor John Smith) ❹, education of the faculty ❺, read the research interests ❻ and the teaching history of Professor John Smith ❼. From here, they directly navigate to the news story (J. S. Receives New Grant) related to this faculty by following a suggested navigation path (e.g., "Related News"). As users need to go *back* to the Ph.D. program in Biology, the existing back button of the browser would force them to backtrack page-by-page through this path and listen to each backtracked page. Alternatively, users could navigate back *by topic* (Figure 1 left) to directly access the last visited topics (not pages): Prof. Smith and the Ph.D. program in Biology. Using a *topic-based back*, users will just visit (in sequence) the current news story, the visited faculty and the program, saving six steps.

Figure 1 left shows how a traditional back strategy (the back of common browsers) would require eight back clicks to get back to the desired page (Description of Ph.D. program in Biology). Topic-based back only requires two clicks, gaining a potential 75% in backtracking efficiency, without considering the decreased demand on cognitive effort (i.e., reducing the need to listen and pay attention to every visited page). Given the highly constrained linearity of the aural medium, this *shortcut* back navigation can be extremely beneficial in aural web browsing for blind users. Topics

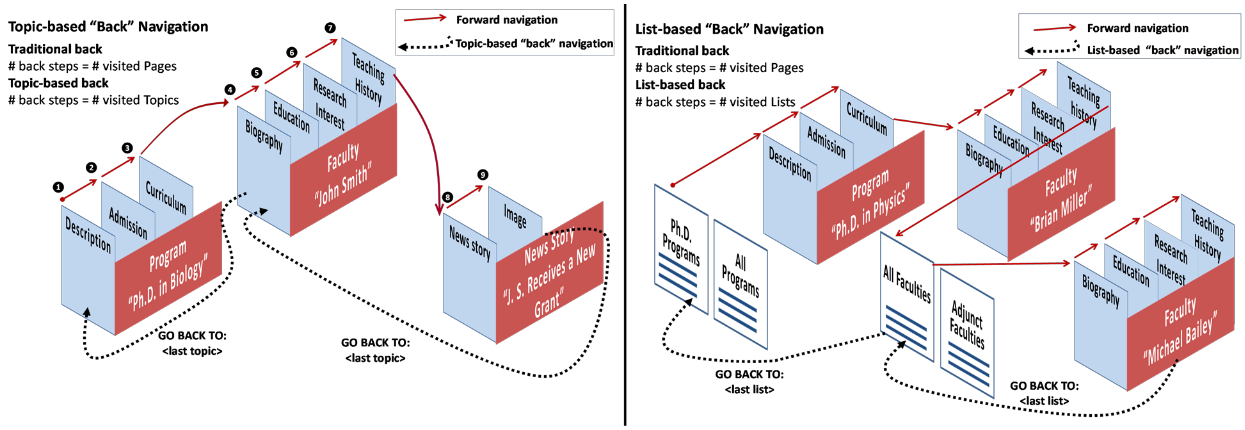

Figure 1. Topic-based back enables users to directly navigate to previously visited *topics*, or cohesive information entities (left); List-based back enables users to directly go back to previously visited *list pages* (right). These navigation shortcuts exploit high-level, generic characteristics of the information architecture of a broad range of content-intensive websites.

are coherent content entities (e.g., the topic *product* in any e-commerce website) that underlie the structure of several information-intensive, highly structured web systems and that can be identified at the conceptual design stage while planning large web information architectures [2] (Figure 1).

3.2 List-based Back Navigation

Imagine a scenario in which users not only traverse content pages, but also list pages, which are the primary mechanism to access content. For example (Figure 1 right), users can visit the list of *Ph.D. Programs*, pick a program, browse its information, and then navigate to the program faculty. From here, users can discover the list of all faculty in the department, pick a faculty and browse his/her detailed page. When users want to go back to the list of *Ph.D. Programs* to pick another program, 12 steps are needed in our example. This means that 12 pages would have to be listened to (at least to recognize the content) in an auditory interface. An efficient aural back does not have to work this way.

Navigation strategies conceptually based on the access structures (*list pages*) would allow users to aurally go *up* directly to the list pages previously visited, thus skipping unnecessary navigation steps through content pages. With a list-based back technique, users can simply backtrack to the list of *Ph.D. Programs* with two steps, gaining a potential 83% in backtracking efficiency, without considering the reduction in cognitive effort. As such, list-based back would be especially beneficial in contexts in which users often go back to previously visited lists to regain orientation and restart a navigation path.

Both conceptual patterns (topic- and list-based back) are applicable to a variety of aural interaction scenarios, and especially to web browsing with screen readers [5, 8, 22].

4. MANIFESTING DESIGNS IN WEBTIME

To explore and evaluate the implications of the proposed navigation shortcuts for screen reader users browsing large information architectures, we have reified topic- and list-based back in Webtime. Webtime is an accessible website prototype targeted to high-school blind and low-vision students on the history of the World Wide Web. The website, intended to be a complementary resource for informal learning, includes the presentation of key historical characters, places, events, as well as landmark ideas and technologies. Sample content for Webtime has been reused from open access resources on the topic, and restructured into a non-trivial web architecture to allow investigators to experiment with the aural navigation patterns. Specifically, the information architecture of Webtime includes five types of topics (people, places, technologies, ideas, and news) and 50 topic instances. It also includes 36 list page instances and 18 types of hypertextual associations (83 instances) (e.g., places related to a technology and ideas related to a news story).

Webtime is optimized for Internet Explorer v8.0 and tested for accessibility with the W3C validator[2]. To auralize content, the prototype has been optimized for Window-Eyes v7.5 screen reader, also based on the software available at the ISBVI. The website has been designed using IDM [2] for the conceptual modeling of the information architecture, MySQL as database technology, and PHP as scripting language. The advanced back navigation strategies are dynamically generated based the matching between the recorded user's backtracking history and the conceptual elements (topic or list) marked on the pages of the information architecture on the server side. In terms of input to control navigation on the user interface, Webtime supports dynamically generated link labels (e.g., GO BACK TO <Topic Name/List Page Name>) as shown in Figure 2. For the purpose of demonstrating the back navigation strategies for dissemination and testing, three versions of Webtime has been instantiated[3], one for topic-based, one for list-based, and one with no shortcuts.

5. EVALUATION HYPOTHESES

Based on the principles of topic- and list-based back navigation as applied to an aural website scenario, we hypothesize that:

H1: With respect to traditional back, topic-based back,

- enables faster navigation to previously visited topics (H1.1)
- yields a better navigation experience (H1.2)
- reduces perceived cognitive effort for screen reader users (H1.3)

H2: With respect to traditional back, list-based back,

[2] http://validator.w3.org/

[3] The accessible Webtime prototypes are available at:
Traditional back: http://discern.uits.iu.edu:8670/NSF_WEB/
Topic-based back: http://discern.uits.iu.edu:8670/NSF_WEB_TB/
List-based back: http://discern.uits.iu.edu:8670/NSF_WEB_UL/
Complete source code, including database and scripts:
http://discern.uits.iu.edu:8670/downloads/WebTime(Feb15_2012).zip

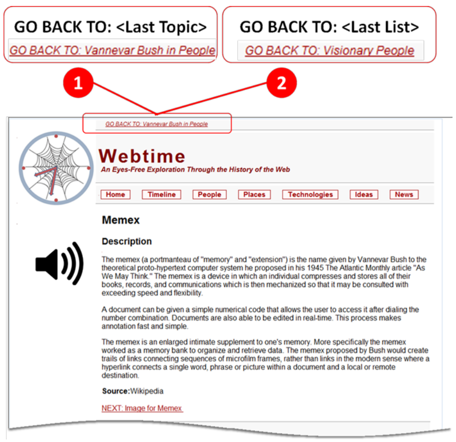

Figure 2. Topic- and list-based back links in Webtime.

- enables faster navigation to previously visited list pages (H2.1)
- yields a better navigation experience (H2.2)
- reduces perceived cognitive effort for screen reader users (H2.3)

6. STUDY DESIGN

To test our hypotheses, we conducted a controlled evaluation study with 10 screen reader users from ISBVI.

6.1 Physical Set Up

The evaluation study was conducted in a controlled lab environment at ISBVI. School's laptops running screen readers were used to let users listen to different versions of Webtime. Participants were familiar with the laptops and keyboard settings used in the study. Participants' interactions with Webtime were recorded using Morae Recorder v3.2.

6.2 Study Variables

The independent variable was the aural navigation strategy, which varied on three levels: traditional back, topic-based back and list-based back. Dependent variables were task efficiency (time-on-task, number of backtracked pages, keystrokes for backtracking), effectiveness (task success rate), self-reported navigation experience and cognitive effort.

6.3 Participants

We recruited 10 blind participants (3 males and 7 females), all high school students from ISBVI that range in age from 14 to 18 years old (M = 16.3; SD = 1.64). All participants spoke English fluently, had at least one year of experience using screen readers, and had no hearing impairments. None of the participants had prior experience with Webtime. For approximately four hours of participation across two days (two sessions of two hours each), each participant received a $50 gift card.

6.4 Procedure

A plenary, half-hour introductory session explained to participants the purpose of the study and the general theme of Webtime. IRB-approved study consent forms were then read aloud, explained, and signed by participants. Each participant went through two testing sessions: for topic- and list-based back respectively. Each session consisted of four parts, executed in this order: (1) training, (2) tasks session, (3) post-test survey, and (4) post-test interview.

6.4.1 Training

For each navigation strategy, participants attended a 45-minute

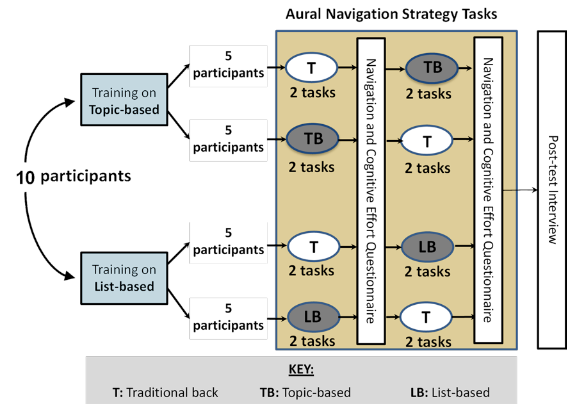

Figure 3. Synopsis of the study design.

training session during which they were briefed about the content sections of Webtime to get familiar with the site. A brief recall of screen commands was also provided and participants executed – each assisted by a researcher – simple navigation tasks on the main menu and a handful of pages. Participants were also introduced to topic-based back in one session and list-based back in another session. Finally, participants could freely browse the site for five minutes on their own.

6.4.2 Task Sessions

For each of the task sessions, participants went through two stages of tests. The first stage used traditional back (T) as a control condition. The second used topic-based (TB) or list-based (LB) as an experimental condition. The order of the stages for traditional and advanced strategies was systematically counterbalanced across all participants to minimize the learning effect. Overall, each participant executed eight tasks (Figure 3), as follows:

a) Two tasks for the topic-based (TB) back condition;

b) Two tasks for the traditional back (T) condition as control for (a);

c) Two tasks for the list-based back (LB) condition;

d) Two tasks for the traditional back (T) condition as control for (c).

Navigation tasks were designed to cover multiple instances of all types of navigation structures relevant for topic- and list-based back. The designed tasks fall under the fact-finding category defined by Kellar et al. [15]. The structure of the tasks (i.e., expected page types in the architecture) was the same across stages. The only difference was the set of instances of topics and list pages that were covered. For example, one of the topic-based tasks (with structural elements in brackets) was the following:

[Access a topic instance and browse its details] Go to the technologies section. Learn more about technology X.

[Navigate to a related topic] Learn more about person Y who has developed the technology X.

[Access a topic instance and browse its details] Go to the "timeline" and see what happened in 1960, 1962, and 1965.

[Back to visited topic] Go back to person Y, without using the backspace key, but using the "go back to" link. Make sure you recognize each page as you navigate back.

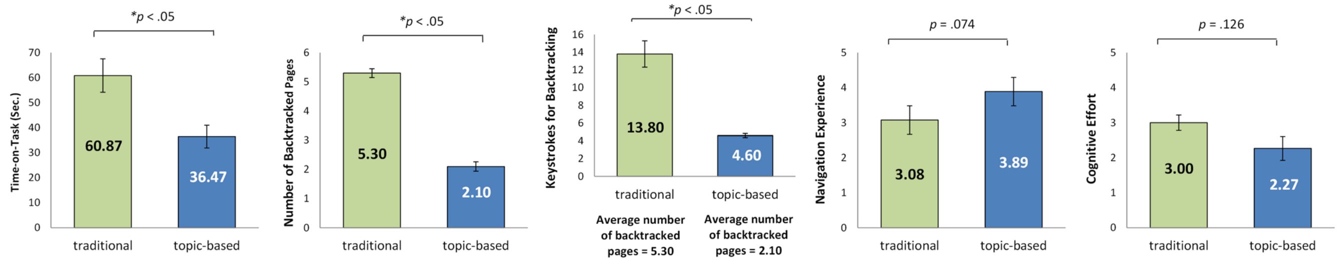

Figure 4. From left to right: topic-based back significantly reduces time-on-task, number of backtracked pages and keystrokes for backtracking. It also yields better ratings for navigation experience and reduces cognitive effort.

6.4.3 Post-test Survey

After each stage, participants rated their navigation experience and cognitive effort using the navigation and cognitive effort-related module of the DEEP usability index [34]. In terms of modality of the survey, eight participants used a braille-embossed version of the survey to read and mark their answers. Two participants preferred to have the questions read aloud to them and voiced their responses.

6.4.4 Post-test Interview

For each of the two back navigation strategies, we asked participants four main questions: (1) Comparing the navigation with backspace to the GO BACK TO function, which one would you prefer to use? Why? (2) If you had to explain to a friend what this new navigation functionality does, how would you describe it in your own words? (3) What difficulties did you experience – if any – when using this navigation function? (4) Do you have any other comments about your navigation experience? Finally, participants were also encouraged to provide more reflective elaboration on the same interview questions via email within one week.

7. ANALYSIS

Wilcoxon Signed-ranks and McNemar tests were used for the quantitative data analysis due to a small sample size. Using these two tests, efficiency and effectiveness of the two novel back navigation strategies were analyzed. McNemar test was used specifically for ordinal data (e.g., success rate). We set the navigation strategy (traditional back vs. topic-based/list-based back) as the within subject factor. Six outcome variables were compared: time-on-task, number of backtracked pages viewed, keystrokes for backtracking, success rate, navigation experience, and cognitive effort. The scales used for measuring navigation experience and perceived cognitive effort (DEEP) were validated using large sample size in a previous study [34].

For the qualitative analysis of the interviews, recurrent themes were extracted and comments were grouped by type. The emerging issues highlight user preferences for the navigation strategies and difficulties faced while using back navigation. For the list-based back navigation, analysis of the data was performed on only nine participants because one recorded video was corrupt.

8. RESULTS

8.1 Topic-Based vs. Traditional Back

8.1.1 Improvement of Time-on-Task

As an indicator of navigation efficiency, time-on-task was operationalized as the amount of time it took users to accomplish a task. Figure 4 shows that, users spent significantly less time in accomplishing the tasks using topic-based back (M = 36.47 sec., SE = 4.57) compared to traditional back navigation (M = 60.87 sec., SE = 6.69) (Z = 2.29, $p < .05$, $r = .73$).

8.1.2 Pages Viewed and Keystrokes for Backtracking

Topic-based back (M = 2.10, SE = .16) significantly reduced the average number of backtracked pages with respect to traditional back (M = 5.30, SE = .15) (Z = 2.85, $p < .05$, $r = .90$). Topic-based back (M = 4.60, SE = .23) also significantly reduced the average keystrokes for backtracking with respect to traditional back (M = 13.80, SE = 1.49) (Z = 2.81, $p < .05$, $r = .89$).

8.1.3 Success Rate

Topic-based back, though not statistically significant ($p = 1.0$), yielded better success rate than traditional navigation. For topic-based back, participants completed 17 out of 20 sessions with full success, while in traditional back navigation 15 out of 20 sessions were completed with full success.

8.1.4 Navigation Experience and Cognitive Effort

Users' navigation experience and perceived cognitive effort in the two navigation conditions were compared in Figure 4. Topic-based back, although not statistically significant, yielded better navigation experience (M = 3.89, SE =.36) than traditional back (M = 3.08, SE = .24) (Z = 1.79, $p = .07$, $r = .57$). Although not statistically significant, topic-based back navigation decreased cognitive effort (M = 2.27, SE = .34) compared to traditional back (M = 3.00, SE = .22) (Z = 1.53, $p = .13$, $r = .48$). These results indicate that topic-based back navigation has the potential to improve the experience of navigating a website using screen reader and may also reduce users' cognitive effort.

8.2 List-Based vs. Traditional Back

8.2.1 Improvement of Time-on-Task

Figure 5 shows that, users spent significantly less time to accomplish the tasks using list-based back (M = 11.08 sec., SE = 1.26) compared to traditional back navigation (M = 53.03 sec., SE = 7.82) (Z = 2.67, $p < .05$, $r = .89$).

8.2.2 Pages Viewed and Keystrokes for Backtracking

List-based back (M = 1.0, SE = .0) significantly reduced the average number of backtracked pages with respect to traditional back (M = 6.06, SE = .13) (Z = 2.81, $p < .05$, $r = .94$). List-based back (M = 2.22, SE = .12) also significantly reduced the average keystrokes for backtracking with respect to traditional back (M = 16.67, SE = 1.12) (Z = 2.67, $p < .05$, $r = .89$).

8.2.3 Success Rate

List-based back, although not statistically significant ($p = 1.0$), yielded better success rate than traditional navigation. For list-based back, participants completed all sessions with full success, while 17 out of 18 sessions were completed with full success in traditional back navigation.

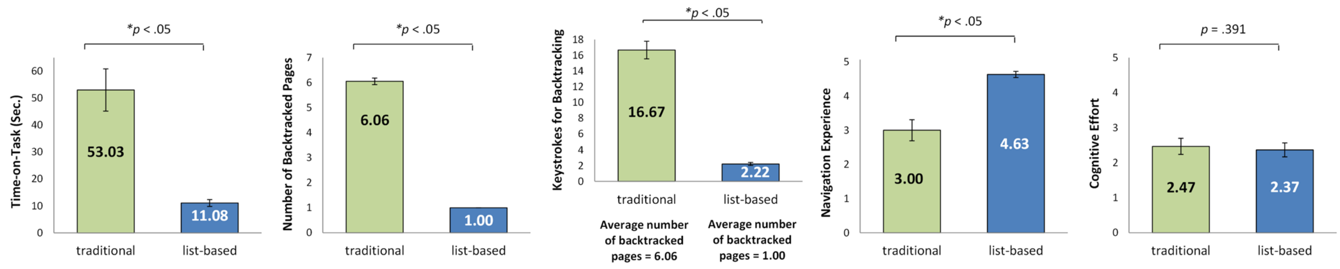

Figure 5. From left to right: list-based back significantly reduces time-on-task, number of backtracked pages and keystrokes for backtracking. It also yields better ratings for navigation experience and reduces cognitive effort.

8.2.4 Navigation Experience and Cognitive Effort

List-based back navigation yielded significantly better navigation experience (M = 4.63, SE = .09) compared to traditional back navigation (M = 3.00, SE = .31) (Z = 2.67, $p < .01$, $r = .84$). Although not statistically significant, list-based back navigation decreased cognitive effort (M = 2.37, SE = .20) than traditional back navigation (M = 2.47, SE = .23) (Z = .86, $p = .39$, $r = .29$). These results indicate that list-based back navigation has the potential to improve the experience of navigating a website using screen reader and may also reduce users' cognitive effort.

9. INTERVIEW FINDINGS

9.1 Navigation Awareness

Participants enthusiastically voiced that the new navigation strategies are faster and easier with respect to page-by-page back, but only a few of them were able to articulate the difference between topic- and list-based back. One out of nine participants (11%) correctly explained the topic-based back, while 44% (4 out of 9) of participants correctly explained the list-based back strategy. The most common explanation of topic-based back revolved around the general notion of *going back where you need to go* (20%, or 2 out of 10). P9: "*[topic-based] takes you back to the more important pieces of the website that you have already visited.*" The most common explanation of list-based back revolved around the generic notion of *previous* page (33%, or 3 out of 9). P3: "*[list-based] just helps you go back to the previous page…I know how it works…I just don't know how to explain it.*"

9.2 User Preferences

Overall, 90% (9 out of 10) of participants preferred topic-based over traditional back, while 10% (1 out of 10) preferred both topic-based and traditional back equally. When asked to compare list-based to traditional back, all participants preferred list-based.

P8: "*I would prefer to use the [topic-based] link, because it is faster than hitting the backspace continuously. You can move through pages faster, too.*" Two out of 10 (20%) participants said that they would like to see topic-based back implemented in all websites they know; while 11% (1 out of 9) said that they would like to see list-based back available on more websites. P6: "*I would like to see [topic-based] in a larger website and see how that works, the intelligence behind this technology is a pleasant idea.*" The same participant suggested to provide a toggle button to switch between topic- and list-based back. P4 mentioned "*I am glad that somebody actually has come up with this option and that somebody out there thinks about blind people and the difficulties we face throughout web search experience. I hope that in the future we, blind people, will have a faster and easier ways on how to access and use Internet.*"

9.3 Overall Difficulties Encountered by Users

Regarding navigation problems, 40% (4 out of 10) of participants said that they had no difficulties using topic-based, while 55% (5 out of 9) of participants had no difficulties using list-based. Thirty percent (3 out of 10) of participants said they had difficulty remembering during the first task that there is a link for topic-based, but they got better with practice. One participant (P2) mentioned that he would "*like to have the list of topics instead of just one topic.*" One participant (P8) mentioned that "*the topic-based back link doesn't engage fast and users need to be familiar with screen readers first to be able to use this new navigation.*"

10. DISCUSSION

10.1 Navigation Efficiency

Our results suggest that topic and list-based enable faster navigation to previously visited pages (Hypotheses H1.1 and H2.1). Topic- and list-based significantly decreased time-on-task, number of backtracked pages and keystrokes for backtracking.

Participants who used topic-based back reached previously visited pages 40% faster than those who used traditional back (Figure 4). Participants who used list-based back completed the navigation tasks 79% faster than those who used traditional back (Figure 5).

Topic-based back saved 60% of backtracked pages compared to traditional back (Figure 4). List-based back saved 83% of backtracked pages with respect to traditional back (Figure 5).

Finally, the last indicator that demonstrates the efficiency improvement is the number of keystrokes used for backtracking. Topic-based back saved 67% of keystrokes compared to traditional back mechanisms (Figure 4); list-based back saved 87% of keystrokes compared to traditional back (Figure 5).

10.2 Navigation Experience

For topic-based, two questionnaire items regarding the perceived navigation experience were significantly higher; "it required only a few steps to accomplish the tasks." and "it was easy for me to return to previous pages." They both confirm that topic-based can make back navigation much easier compared to traditional back. Topic-based also requires only a few steps or pages to go back.

For list-based, all the questions were rated significantly high, with the highest being: "returning to previous pages was immediate," "it required only a few steps to accomplish the tasks" and "it was easy for me to return to previous pages." These three questions also confirm that participants using list-based need a few steps or pages to go back to the list, making it easier to navigate compared to traditional back navigation. This result confirms hypotheses H1.2 and H2.2, namely that topic- and list-based yield better navigation experience.

10.3 Cognitive Effort

Our findings show that both advanced navigation strategies, decreased cognitive effort, although not significantly. For topic-based back, two questionnaire items decreased in rating more compared to traditional back: "using this website was effortless" (topic-based: M = 2.90, SE = .46; traditional: M = 3.70, SE = .37) and "using this website made me feel tired" (topic-based: M = 2.10, SE = .43; traditional: M = 3.00, SE = .37).

For list-based back, one questionnaire item's rating decreased the most compared to traditional back: "using this website made me feel tired" (list-based: M = 1.90, SE = .41; traditional: M = 2.20, SE = .33). This result confirms hypotheses H1.3 and H2.3, namely that topic- and list-based back reduce perceived cognitive effort.

10.4 Users' Mental Model vs. Designer Model

The interview findings show that blind users' mental model is different from the designer's model of topic- and list-based back. Participants do not fully articulate the difference between advanced navigation strategies and consider them as fulfilling the same basic function of back navigation shortcut (Figure 6). One possible reason could be that blind users did not distinguish between different page types (e.g., topic and list pages).

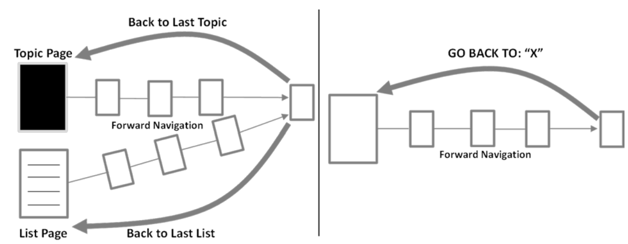

Figure 6. Designer model (left); users' mental model (right).

In spite of the limitation of blind users' mental model, the efficiency and effectiveness are maintained high using these two advanced navigation strategies.

10.5 Validity and Limitations of the Study

10.5.1 Internal Validity

Several tactics were used to maximize internal validity. First, a within-subject design was developed in which traditional and advanced navigation strategies were compared to collect both performance data and self-reported, subjective experiences. Second, to alleviate the learning effect within subjects, a consistent group training session was conducted with participants before the experiment commenced so that participants could reach a common threshold of experience with the site. Third, the order in which the traditional and advanced navigation conditions were used was also counterbalanced across participants. Thus, the participants were not always exposed to the traditional navigation strategy first and advanced strategies after. This prevented the participants from realizing that higher ratings were expected for the advanced strategies.

10.5.2 External Validity

The objective of these two advanced navigation strategies is not to substitute the existing back links of a given web application, but rather to assist blind users to navigate at a higher conceptual level than it is currently supported. Fundamentally, both topic- and list-based complement current research on strategies to structure the aural page [25] by operating at the level of the information architecture of the site.

A potential limitation of the proposed back navigation shortcuts is their *applicability* to a broad range of web applications. Topic- and list-based exploit two high-level, generic characteristics of the information architecture of a broad range of content-intensive websites. The concept of *topic* is not a unique to a specific design model [2], but it captures the generic notion of cohesive, information entity type or object which underlies web applications with highly-structured, database-driven information architectures. Examples of web application domains where topics can be easily identified include e-Commerce (e.g., *product*), institutional and educational websites (Figure 1), news casting (e.g., *news story*), entertainment (e.g., *movie*, *actor*), tourism (e.g., *place*, *attraction*, *restaurant*, *tour*), healthcare (e.g., *patient, illness, tip, drug*), and many others. List pages are even easier to identify, and do not depend on having topics or a structured information architecture. Designers who have experience working on large, engineered web information architectures (e.g., thousands of pages), or are familiar with common design patterns [32], will be able to recognize a mapping between their websites' information architecture and the proposed navigation semantics.

With this in mind, it is important to note that these aural navigation shortcuts can be applied to most structured information architectures, with *two exceptions*. First, websites with very simply structured topics (e.g., a one page description of a product) will lend themselves to a much smaller gain in navigation steps with topic-based. Second, a website with very few pages (e.g., 6-10 or so) will yield much shorter user's navigation trails, and therefore users could more efficiently go back to the home page to retrieve the visited page rather than using a topic- or list-based short-cut. Finally, although our controlled study design investigated topic- and list-based as separate shortcuts, an envisioned role of these strategies is to work *in combination* to supplement current back mechanisms in large-scale web systems.

11. CONCLUSIONS AND FUTURE WORK

We hypothesized that navigation strategies that operate at a higher level of abstraction than the single page increase the efficiency and effectiveness of web browsing for screen reader users. To test this hypothesis, we examined and reified two novel solutions for back navigation, topic- and list-based back, in Webtime, an accessible website targeted to blind and low-vision web users. Topic-based back leverages the notion of topic to quickly navigate back to previously visited content pages, thus skipping lists and secondary, content detail pages. As complementary strategy, list-based back enables to directly navigate back to visited list pages across several navigation trails. Our findings suggest that the proposed strategies – when compared to existing page-level back mechanisms – result in significant enhancements in both navigation efficiency and effectiveness. A question remains: how can we further facilitate the adoption of such navigation shortcuts among web designers? Providing an engine to automatically crawl a website and identify topics and list-pages (e.g., based on recurrent document structures and page cues) could be an approach to pursue. The outcome of this process can be then used to automatically generate the topic- and list-based links for a broad range of websites.

Based on the encouraging results presented in this paper, we are exploring additional ways to interact more naturally with *aural information architectures*. For example, previous work on using speech commands to navigate the structure of a document [13, 18] showed that sighted users enjoyed this interaction mode. A current line of work is to investigate high-level vocabularies and techniques to enable screen reader users to interact with vocal commands on large websites.

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