Aural Browsing On-The-Go: Listening-based Back Navigation in Large Web Architectures

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ABSTRACT
Mobile web navigation requires highly-focused visual attention, which poses problems when it is inconvenient or distracting to continuously look at the screen (e.g., while walking). Aural interfaces support more eyes-free experiences, as users can primarily *listen to* the content and occasionally look at the device. Yet, designing aural information architectures remains a challenge. Specifically, back navigation is inefficient in the aural setting, as it forces users to listen to each previous page to retrieve the desired content. This paper introduces *topic-* and *list-based back*: two navigation strategies to enhance aural browsing. Both are manifest in Green-Savers Mobile (GSM), an aural mobile site. A study (N=29) compared both solutions to traditional back mechanisms. Our findings indicate that topic- and list-based back enable faster access to previous pages, improve the navigation experience and reduce perceived cognitive load. The proposed designs apply to a wide range of content-intensive, ubiquitous web systems.

Author Keywords
Aural web; mobile web; info architecture; back navigation.

ACM Classification Keywords
H.5 [Information Interfaces and Presentation];

INTRODUCTION
A student walks to school while listening to music; a mom jogs in the park while listening to her favorite podcast; a scientist walks to lunch while listening to the latest news.

These situations share a common thread: listening to digital content in a mobile setting. Whereas existing audio content follows an elementary, linear structure (e.g., playlists, podcasts or audio books), it is much less obvious to design *aural* interactions for highly-structured, hypertextual content, such as a large website. This would call for investigating the interplay among listening to content, being on-the-go, interacting (occasionally) with a mobile device, and navigating a large information architecture (Figure 1).

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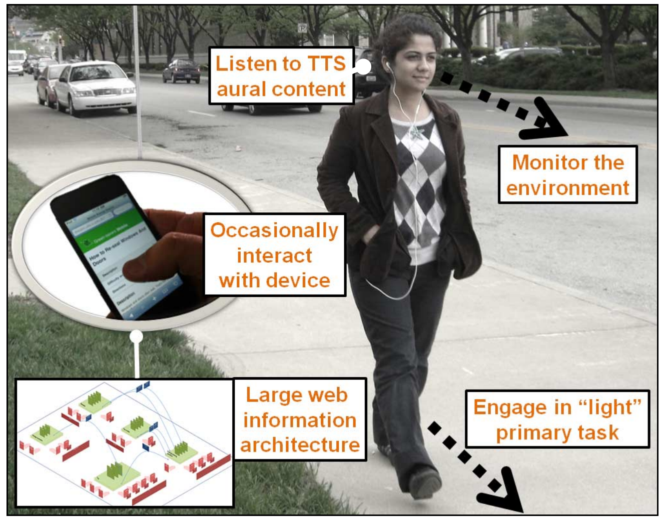

Figure 1. A mobile scenario for browsing aural websites.

Aural interfaces have shown to have potential to support eyes-free experiences [24, 25], as users can mainly *listen* to content (e.g., in Text-To-Speech form) and occasionally *look* at the mobile device. A recent study on driving scenarios indicates that *audio-based* interfaces – though slower to interact with – can be less distracting from the primary task (e.g., monitoring the environment) compared to visual interfaces [8]. Yet, one of the most perplexing challenges of designing effective aural interfaces is to understand the navigation issues in large information architectures [5, 6]. The aural perceptual channel, in fact, is much narrower than our visual bandwidth; this makes the aural navigation of complex hierarchical and hypertextual structures a very difficult and frustrating task [1, 5, 26].

Aurally browsing non-trivial web architectures is especially cumbersome in those frequent situations in which users need to go *back* to previously visited pages. In visual navigation, users can easily master the flow of pages through at-a-glance page scanning. Aural back navigation, however, becomes quickly unmanageable when many pages need to be backtracked: each non-useful back click is a detrimental waste of time and cognitive effort, as the user is forced to *listen to* some part of the page to recognize it [12]. The structural linearity of audio, combined with the rigid linearity of existing web history strategies, easily leads to ineffective aural experiences [3]. How can the experience of back navigation be improved in aurally browsing a

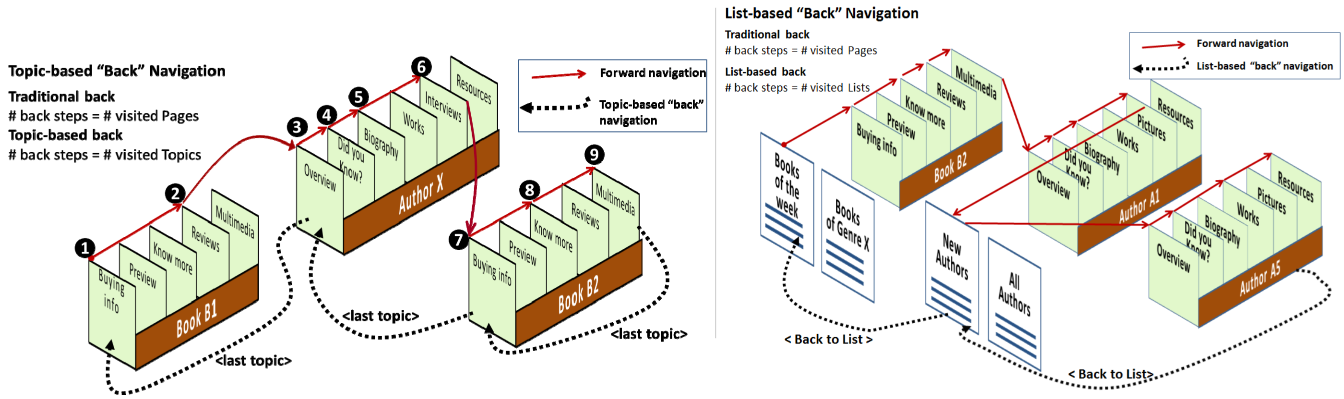

Figure 2. Topics (rather than pages) are the cognitive landmarks in topic-based back navigation (left); list-based back enables users to directly navigate to previously visited list pages (right).

mobile web application? How can people interact with the aural backtracking history while on the go?

To address these questions, this paper introduces and evaluates *topic-* and *list-based back*, two conceptual design strategies to support effective "back" navigation in complex aural information architectures, especially for mobile contexts. Both aural navigation strategies are manifest in Green-savers Mobile (GSM in short), an aural mobile website. GSM was used to set up a controlled evaluation study (N=29) in which participants browsed aural content in a simulated walking environment using either the advanced navigation strategies or a traditional "back" mechanism for aural browsing tasks of equivalent complexity. To control the navigation, we combined the design strategies with two "commodity" input modalities commonly available on smart phones (clicking on an explicit link, or using custom touch gestures). We measured task efficiency, navigation experience and perceived cognitive load for each condition. In short, our findings suggest that the advanced navigation solutions, when each compared to traditional back mechanisms, enable faster access to previous pages, improve the navigation experience, and reduce cognitive load. Whereas these strategies might make little difference for the visual web, our work shows that they are enhancing navigation performance and experience in auditory browsing, especially when audio is experienced in the pervasive mobile context (with sporadic interaction with the device and dual-task situations). In the following sections we illustrate the aural browsing strategies, the study design, and the results. We then discuss the implications and limits of our research to advance the design of the aural web.

BACK BROWSING STRATEGIES FOR THE AURAL WEB

Topic-based Back Navigation

In very large web applications, the change of navigational context (e.g., reaching a new type of content or a new section) is not taken into consideration by current history or backtracking strategies (e.g., the back button of the browser), that simply model every navigation unit as a "page." Collections of pages, however, are commonly "held" together and conceptually designed to represent a coherent information entity, or "topic". For example, in Amazon.com, a main topic is a "book." A book topic generally consists of a number of pages, such as buying information, customer reviews, and a book preview. Users traverse pages, and in traversing pages, they navigate topics. Aural users can benefit by navigating *back through topics* instead of through pages, as topics represent clear landmarks for new content and navigation contexts.

Imagine a scenario in which users are moving from the "buying info" page ❶ of book B1 (see Figure 2 left) to the book reviews ❷. From there, they navigate to the book's author ❸, listen to trivia ❹ and biographical information about the author ❺, listen to an interview ❻, and directly navigate to another book written by the same author by following a suggested navigation path (e.g., "see other books of this author"). As users need to go "back" to the first visited book by using existing back mechanisms, they would need to backtrack *page by page* through this path, with the known detrimental consequences of "listening" to every previous page. Instead, by using a *topic-based navigation strategy* (Figure 2 left), users can directly access the last *visited topics* (not pages), and thus visit (in sequence) the current book, the visited author and the first book. Topics are defined at conceptual design time during the planning of large web information architectures [3].

In the example of Figure 2 (left), a traditional back strategy (the back of common browsers) would require eight back clicks to get back to the desired page (Buying info of Book B1). Topic-based back would only require three clicks, gaining a potential 62% in backtracking efficiency, without considering the decreased demand on cognitive effort (i.e. removing the need to listen and pay attention to every visited page). Given the constrained linearity of the aural medium, this "shortcut" back navigation can be extremely beneficial in aural, mobile situations.

List-based Back Navigation

Let us now consider a complementary perspective. Users not only traverse content (topics), but also *list pages,* which are the fundamental mechanism to access content. For example (Figure 2 right), users can visit the page "Books of

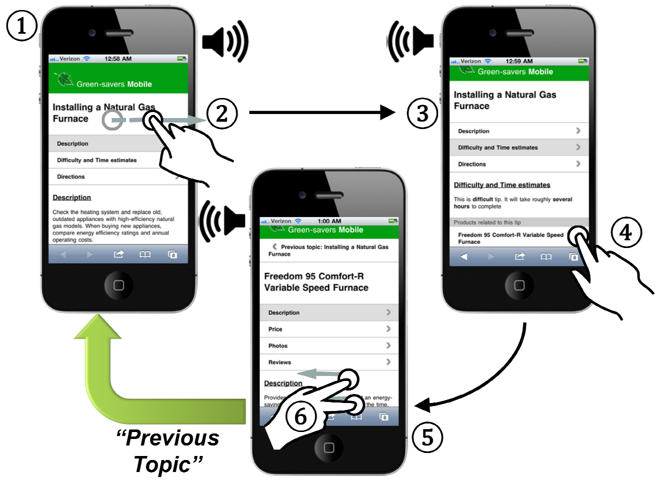

Figure 3. Topic-based back with custom gesture: ❶ Green Tip 1, Description; ❷ Move to ❸ Tip 1, Time estimates; ❹ Go to a related product; ❺ Product 1, Description; ❻ Two-finger swipe left to go back to Tip 1. Icons from [14].

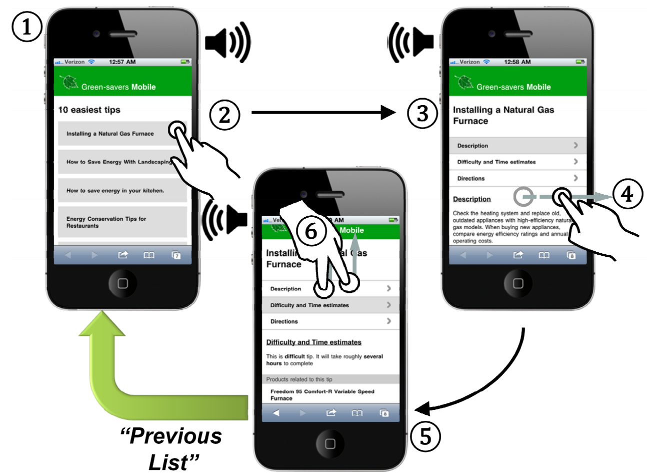

Figure 4. List-based back with custom gesture: ❶ List of tips ❷ Choose the first tip; ❸ Tip 1, Description; ❹ Go to the next section of the tip; ❺ Tip 1, Time estimates; ❻ Two-finger swipe up to go back to the previous list (list of tips).

the Week”, pick a book, browse its details, navigate to the author, discover from here a list of emerging authors, choose another author, and browse her biography. If users want to go back to the “Books of the Week” list to pick another book, 11 steps are needed in our example. This means that 11 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 (topic) pages. With a *list-based back*, users can simply backtrack to the list of “Books of the Week” with 2 steps, gaining a potential 81% 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, such as the use of screen readers [1, 3, 6, 20], as well as for aurally navigating a large website on-the-go using a mobile device.

REIFYING DESIGNS

To investigate and evaluate the implications of these navigation strategies on the interplay between aural mobile browsing and interacting with complex architectures, we have reified topic-based back (Figure 3) and list-based back (Figure 4) in GSM, an aural web-based mobile application prototype on energy saving tips and green products for the home (http://discern.uits.iu.edu:8670/NSF_MOBILE/). This mobile site was developed to demonstrate aural mobile navigation in a non-trivial, web information architecture. The information architecture of GSM includes 4 types of topics (tip, product, tax credit, and rebate), overall 65 topic instances, 43 list page instances, and 6 types (64 instances) of hypertextual associations (e.g., products related to a tip, tips related to a product, rebates available for a product).

GSM is optimized for touch-screen mobile devices, specifically Apple’s iPhone or iPod Touch, with iOS 4.1. To auralize content, GSM features dynamic, real-time text-to-speech (TTS) of page content and links. The custom TTS script, which is based on the API of the iSpeech service (www.ispeech.org), converts the text visible on the screen to audio, which is played back to the user in the same order in which it appears on screen. The back navigation strategies dynamically populate the user’s backtracking history based on the current browsing session. Navigation functions have also been parameterized to alternatively exhibit topic- or list-based behavior. In terms of input to control navigation, GSM supports explicit link labels (e.g., Go back to <List Page Name>), and, alternatively, custom touch gestures (see Figure 3 and 4) to alleviate the demand of focused visual attention to the device.

EVALUATION HYPOTHESES

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

H1: With respect to traditional back, *topic-based back* enables faster navigation to previously visited content pages, yields a better navigation experience and reduces perceived cognitive load.

H2: With respect to traditional back, *list-based back* enables faster navigation to previously visited list pages, yields a better navigation experience and reduces perceived cognitive load.

H3: The proposed custom gestures support topic-based navigation better than label clicking.

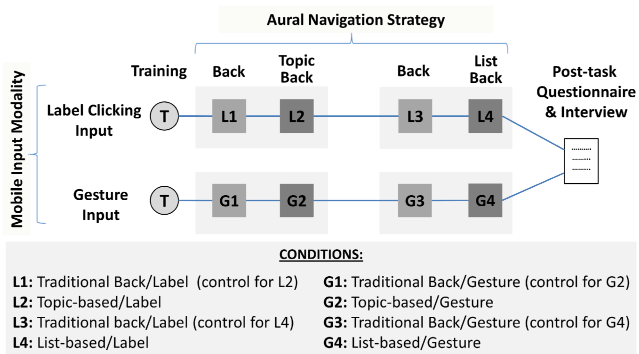

Figure 5. Synopsis of the study design.

H4: The proposed custom gestures support list-based navigation better than label clicking.

STUDY DESIGN

Physical Set Up

The evaluation study was conducted in a controlled environment, where we set up an 89-foot long path that users had to walk on while executing aural browsing tasks. The path included 10 sharp turns and 5 stop signs (on the ground) to simulate a real-world scenario in which people are required to avoid other people or objects in their way (Figure 6 left). We recorded the interaction with GSM (through a mounted video camera) and the walking behavior along the path (through a distant observer with video camera). Participants were encouraged to walk on the path as naturally as possible, and listen to the TTS content and links provided by the application. They were asked to only look to the device when necessary to activate a link.

Study Variables

The independent variables were the aural navigation strategy (traditional back, topic-based back, or list-based back) and input modality (custom gesture input or label clicking). Dependent variables were task efficiency (time-on-task, number of pages viewed), effectiveness (task success rate), degree of distraction from walking path (missed stop signs and steps out of the path), self-reported navigation experience and perceived cognitive load.

Participants

We recruited 29 participants (14 males and 15 females), all undergraduate students from a large Midwestern university; all of them spoke English fluently, and had no hearing or walking impairment. Participants were all daily users of Apple iPhone or iPod Touch. For approximately 60 minutes of participation, each participant received a $15 gift card.

Procedure

Participants were randomly assigned to either gesture-input group (G) or label clicking group (L). Participants in either group individually attended a 10-minute basic training (T) session in which they were briefed about the general content of GSM and the navigation features available. Participants were then introduced to both topic- and list-based back for 3-4 minutes and were given approximately

Figure 6. Simulated path that users walked while doing tasks (left); capturing participant's navigation behavior (right).

15 minutes to practice the two navigation strategies and input modalities on their own.

The gesture group (G) was instructed to use the custom finger gestures to activate topic- and list-based back. For the control group (traditional back), users were instructed to go back to previously visited pages using one finger swipe right. The label group (L) was instructed to click on an explicit link labels when available (i.e., anchor: Back to <*topic name*>) to perform the same back operations. Both groups went through four stages of tests – two tasks per stage – totaling eight tasks per participant (see Figure 5). The first stage included traditional back/label (L1) and traditional back/gesture (G1), both as control conditions for topic-based navigation. The second stage included topic-based/label (L2) and topic-based/gesture (G2), both as experimental groups for topic-based navigation. Stage three and four covered traditional back/label (L3) and traditional back/gesture (G3) as control for list-based navigation. List-based/label (L4) and list-based/gesture (G4) were the experimental groups for the list-based navigation strategy.

Fourteen participants went through stages in an order of 1, 2, 3, and 4, while 15 participants follow the order of 3, 4, 1, and 2. 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 of Kellar et al. [17]. Appendix A reports two examples of the tasks used, one for topic-based navigation and one for list-based navigation. The structure of the tasks (i.e., expected page types in the architecture) is the same across stages. The only difference is the set of *instances* of topics and list pages that were covered.

During each task, participants were asked to use the application while walking on the predefined path marked with tape. Deviations from the line or missed stop signs (breaks on the course) during the task were recorded as distractions. Three types of distraction indicators were captured: 1. *number of stop signs missed*: the number of stop signs that a user walked across without stopping; 2. *number of step-outs*: the number of times that a user stepped out of the predefined path; and 3. *unnecessary stop-time*: the amount of time users spent standing still when they were not supposed to. After each stage, participants rated their navigation experience using the navigation-related module of the DEEP usability index [34]; they also

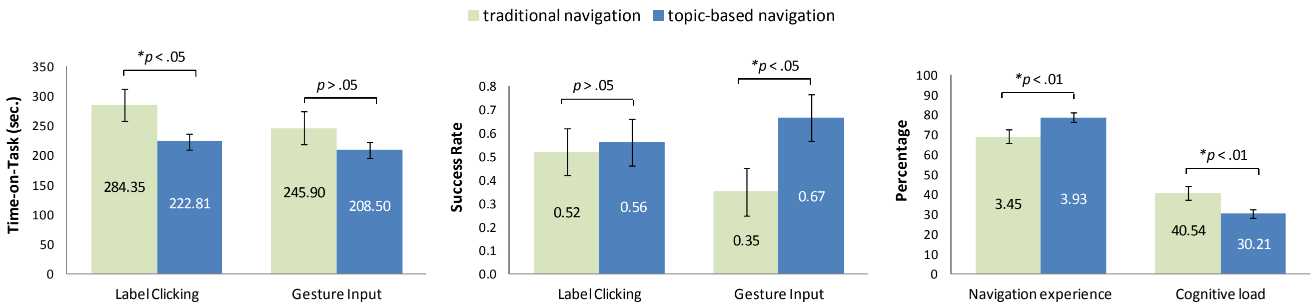

Figure 7. Topic-based back significantly reduces time-on-task when label clicking input is used (left); significantly increases success rate when gesture input is used (middle); and yields better ratings for navigation experience and cognitive load (right).

rated their perceived cognitive load on the NASA TLX scale [15].

In a post-test interview, participants were asked three main questions about their navigation experience: (1) *Which of the three navigation strategies – if any – did you find most helpful in completing your tasks? (2) Please explain in your own words what each strategy does; (3) What difficulties – if any – did you encounter in using the back navigation?*

ANALYSIS

For the quantitative data, 2 × 2 mixed-model ANOVAs were used to analyze the efficiency and effectiveness of the two novel back navigation strategies, and the effect of the input type. We used the navigation strategy (traditional back vs. topic-based/list-based back) as the within subject factor and the input type (label clicking vs. gesture input) as the between subject factor. Six outcome variables were compared: time-on-task, success rate, distractions, pages viewed, navigation experience, and cognitive load. The scales used for measuring navigation experience (DEEP) and perceived cognitive load (NASA TLX) were reliable in all the experimental conditions (Cronbach's Alpha > .82). This indicates that they were good instruments for capturing the factors of the user experience we set out to measure. For the qualitative analysis of the interviews, we extracted recurrent themes and grouped comments by type. The emerging issues highlight user preferences for the navigation strategies, and difficulties faced while using back navigation in combination with the input modalities.

RESULTS

Topic-Based Back vs. Traditional Navigation

Topic-based Back Reduces Time-on-Task

As indicator of navigation efficiency, we operationalized time-on-task as the amount of time it took users to either accomplish or give up on a task. Average time-on-task differs significantly between topic-based and traditional back ($F_{(1,\ 26)} = 6.75$, $p < .05$, $\eta^2 = .206$). Users spent significantly less time to accomplish the tasks using topic-based back (M = 215.65 sec., SE = 9.48) than using traditional back navigation (M = 265.12 sec., SE = 18.73).

No significant interaction was found between navigation strategy and input type. A special pattern, however, was detected: topic-based back only significantly reduced time-on-task in the label clicking condition, but not in the gesture input condition (see Figure 7 left).

Topic-based Back with Gesture Increases Success Rate

As indicator of navigation effectiveness, we measured users' task performance by either pass (full completion of the task) or fail (partial completion, completion with assistance, give up, or missing target). The success rate was calculated by averaging the scores of the related tasks. Success rate did not differ significantly between topic-based and traditional back ($F_{(1,\ 26)} = 4.16$, $p > .05$, $\eta^2 = .138$). Nevertheless, the success rate using topic-based back (M = .58, SE = .07) was still much higher than using traditional back (M = .42, SE = .07). Although no significant interaction was found, we noticed that topic-based back significantly increased the success rate in the gesture input condition, but not in the label clicking condition (see Figure 7 middle). Moreover, the combination of topic-based back and gesture input yielded the best success rate (67% on average) across conditions.

Distraction from Walking Task

Unnecessary stop-time was significantly reduced using topic-based back ($F_{(1,\ 26)} = 6.8$, $p < .05$, $\eta^2 = .207$) (Figure 8). Topic-based back reduced (although not significantly) both the number of stop signs missed ($F_{(1,\ 26)} = .23$, $p > .05$, $\eta^2 = .009$) and the number of step-outs ($F_{(1,\ 26)} = .14$, $p > .05$, $\eta^2 = .005$). No significant interaction between navigation strategy and input type was found for each of the three distraction indicators (number of stop-signs missed, number of step-outs, and unnecessary stop-time).

Number of Pages Viewed

Number of pages viewed did not differ significantly between topic-based back and traditional back ($F_{(1,\ 26)} = .05$, $p > .05$, $\eta^2 = .002$). On average, the number of pages viewed using topic-based back (M = 17.50, SE = 1.14) was only slightly less than the number viewed using traditional back (M = 17.13, SE = .88). There was also no significant interaction between navigation strategy and input type.

Better Navigation Experience and Reduced Cognitive Load

Users' navigation experience and perceived cognitive load in the two navigation conditions are compared in Figure 7

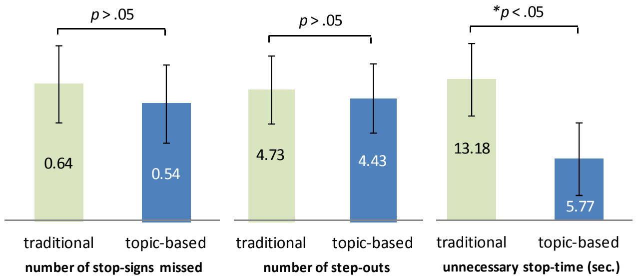

Figure 8. Topic-based back partially reduces distraction, especially the number of unnecessary stops (when users stop to focus on the device).

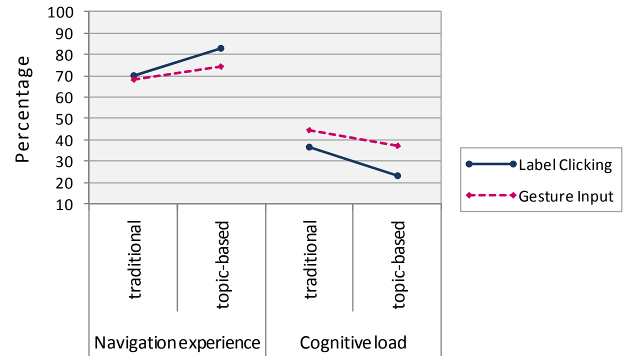

Figure 9. Topic-based back used with label clicking yields better ratings for navigation experience and cognitive load.

(right). Regardless of the input type used, users had significantly better navigation experience using topic-based back (M = 3.93, SE = .12) than traditional back (M = 3.45, SE = .18) ($F_{(1, 27)} = 9.22$, $p < .01$, $\eta^2 = .255$). Moreover, users' cognitive load was significantly higher in the traditional back (M = 40.54, SE = 4.35) than in the topic-based back condition (M = 30.21, SE = 3.17) ($F_{(1, 26)} = 10.47$, $p < .01$, $\eta^2 = .287$). These results indicate that topic-based back navigation has the potential to improve the experience of navigating an aural website and reduce the cognitive load in accomplishing aural browsing tasks.

No significant interaction between navigation strategy and input type was found for either navigation experience or cognitive load. It is worth noting, however, that gesture input significantly worsened the perceived cognitive load in topic-based back (M = 37.72, SE = 5.36; t = 2.47, $p < .05$) with respect to label clicking (M = 22.98, SE = 2.66). In addition, when label clicking input was used, topic-based back enhanced navigation experience and reduced cognitive load to a higher degree than when gesture input was used. This is clearly indicated by the different slopes between the solid and the dotted lines in Figure 9. In sum, the above evidence suggests that gesture input might not work as well as label clicking for the topic-based back navigation.

List-Based Back Navigation vs. Traditional Navigation

List-based Back Reduces Time-on-Task

Time-on-task differed significantly between list-based back and traditional back ($F_{(1, 26)} = 16.94$, $p < .05$, $\eta^2 = .394$). It took users significantly less time to accomplish the tasks using list-based back (M = 130.00 sec., SE = 9.09) than using traditional back (M = 173.38 sec., SE = 9.75). No significant interaction was found between navigation strategy and input type.

List-based Back and Success Rate

Success rate did not differ significantly between the two navigation strategies ($F_{(1, 26)} = 2.97$, $p > .05$, $\eta^2 = .102$). Nevertheless, the success rate using list-based back (M = .57, SE = .08) was still much higher than using traditional back (M = .39, SE = .08). Significant interaction was found between navigation strategy and input type ($F_{(1, 26)} = 4.27$, $p < .05$, $\eta^2 = .141$). List-based back significantly increased success rate with label clicking, but not with gesture input (see Figure 10 left). The combination of list-based back and label clicking input yielded the best success rate (71% on average) across all conditions.

Distraction

Although not significant, list-based back reduced the number of stop-signs missed ($F_{(1, 25)} = .49$, $p > .05$, $\eta^2 = .019$), the number of step-outs ($F_{(1, 25)} = 2.81$, $p > .05$, $\eta^2 = .101$) and the unnecessary stop-time ($F_{(1, 25)} = 3.87$, $p > .05$, $\eta^2 = .134$) (Figure 10 middle). No significant interaction between navigation strategy and input type was found for each of the three indicators.

Number of Pages Viewed

The number of visited pages did not differ significantly between the two navigation strategies ($F_{(1, 26)} = 2.27$, $p > .05$, $\eta^2 = .080$). Nevertheless, on average, users still browsed less pages using list-based back (M = 12.46, SE = .80) than using traditional back navigation (M = 13.98, SE = .83). No significant interaction was found by taking into consideration the input type used.

Better Navigation Experience and Reduced Cognitive Load

Regardless of input type, users had significantly better navigation experience using list-based back (M = 4.19, SE = .11) than traditional back (M = 3.54, SE = .15) ($F_{(1, 27)} = 18.67$, $p < .01$, $\eta^2 = .409$). Additionally, users' cognitive load was significantly higher in the traditional back condition (M = 38.94, SE = 3.55) than in the list-based back condition (M = 23.62, SE = 2.85) ($F_{(1, 24)} = 14.07$, $p < .01$, $\eta^2 = .370$). These results indicate that, list-based back navigation has the potential to improve the experience of navigating a website and reduce the cognitive load in aural browsing tasks.

Findings from post-test interviews

Emerging but Not Translucent Mental Model

The navigation strategies were not fully understood by all participants. Three of 29 participants (10%) correctly explained the topic-based back, while 16% (5 out of 29) correctly explained the list-based back strategy. For both advanced navigation strategies, 30% (9 out 29) of participants gave partially complete answers, while the remaining 44% (13 out of 29) gave confusing answers, showing difficulty in articulating an accurate mental model of the navigation mechanisms that they used.

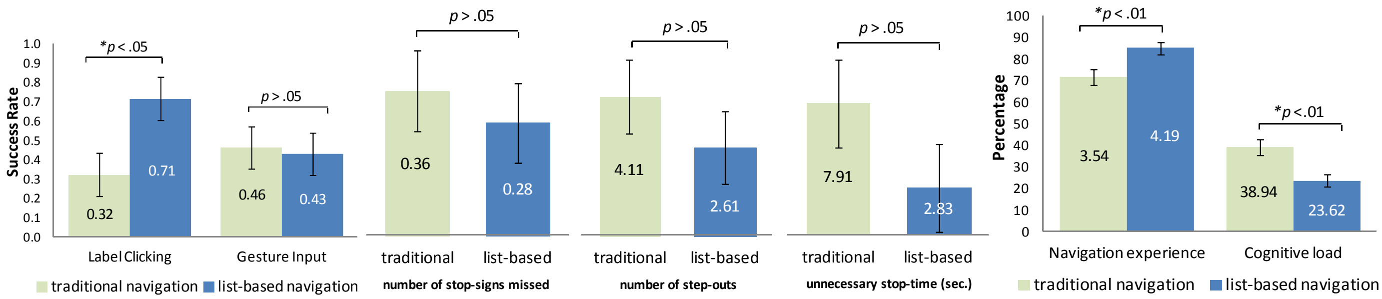

Figure 10. List-based back significantly increases success rate when label clicking input is used (left); reduces distractions (middle); and yields better ratings for navigation experience and perceived cognitive load (right).

The most common explanation of topic-based back revolved around the general notion of "last" page (21%, or 6 out of 29), or "main" page (10%, or 3 out 29). P3: *"[List-based back] is a more detailed version of the back button"*. P8: *[Topic-based back] sends you back to the main page"*. Other comments (accounting for 25% of participants) gave more accurate explanations. P22: "*[List-based back] with a single click takes you to a previous list"*. P17: *"[Topic-based back] navigates through topics you visited"*. Overall, although list-based back was better understood than topic-based navigation, it is clear that users did not immediately conceptualize the new strategies in their key mechanisms.

List-based Back Preferred over the Other Strategies

Overall, 55% (16 out of 29) preferred the list-based back more than traditional and topic-based back navigation. Topic-based back was preferred by 25% (7 out of 29), while 10% (3 out of 29) preferred both advanced navigation strategies equally. The remaining 10% (3 out of 29) preferred the traditional back. Some users' comments reveal that they prefer and understand list-based back better than topic-based back navigation. Some of the comments included: P12: *"[List-based back] is easy to navigate, straight to the point"*; P18: *"topic-back was a bit hard to find"*.

Overall Difficulties Encountered by Users

In terms of navigation problems, 24% (7 out of 29) of participants had no difficulties whatsoever. The remaining participants had difficulties of different sources, such as: non-responsive touch for gesture and label clicking alike (24%, 7 out of 29), hard-to-hit small buttons (14%, 4 out of 29), confusing website layout (14%, 4 out of 29) and occasional application freezing (10%, 3 out of 29). Finally, two participants suggested including also a *forward* topic- and list-based navigation. This would facilitate back *and forth* movements across the trail of topics and lists.

DISCUSSION

Topic-based and List-based Back Increase Efficiency

Our study confirms hypotheses H1 and H2, as it shows that both topic-based back and list-based back are important time-savers in aural mobile browsing. On average, compared to traditional back, topic-based back saved about 49.47 seconds, while list-based back saved about 43.38 seconds. Since each task was supposed to be completed within approximately 4-5 minutes, a 40 to 50 seconds reduction is a 17% gain in navigation efficiency. This is an important gain, but it is much lower than what we anticipated based on the conceptual navigation modeling (Figure 2), which did not consider the mobile setting, input type, the prototype limitations, and human error.

Gesture Semiotics in Aural Mobile Contexts

As we consider the input type used, an interesting finding emerges: topic-based back significantly increased success rate only when gesture input was used, whereas list-based back was effective only with label clicking. This finding can be interpreted by considering the semiotic of our custom gestures [2], i.e., whether the gesture used transparently conveys the intended functional meaning.

On the one hand, our data suggest that "two-finger swipe left" gesture successfully conveys the meaning of "moving back to a previously visited *topic*". Participants remembered to use it and used it accurately. On the other hand, the "two-finger swipe *up*" gesture used to convey "last-list" was probably a poor design decision. The original rationale for this gesture was to resemble the "move up" paradigm used in hierarchical directories. The semiotics of this custom gesture, however, was not transparent enough to immediately convey its functional meaning, and this caused difficulties for the users during the test. As a consequence, *label clicking* for list-based navigation offered users a more transparent semiotics or information scent [28], as it provided an explicit name indicating the target destination (i.e., the actual title of the last list page).

For the topic-based back navigation, users were more successful in completing the tasks using gesture, though it required relatively high cognitive load. This shows that users can perform better using gesture in topic-based back, but they need more time to get adjusted to use the gesture. These findings resonate with those of "Slide Rule" [16], in which participants were faster but made more errors using a touch screen than using physical buttons. Collectively, our results partially confirm hypothesis H3; list-based back, however, is more effective when label clicking is used. Therefore, hypothesis H4 is not supported by our findings.

More than Expected Page Visits

Unexpectedly, neither of the two advanced navigation strategies significantly reduced the number of pages visited to accomplish the tasks. The reason behind this may be two-fold. First, the implementation of the custom gesture on the prototype pages had some bugs that occasionally caused the unresponsiveness of gesture interaction. Thus, as users clicked incorrect links or used a gesture unintentionally, the number of pages visited increased. Second, some users failed to notice the correct cue on the page and started browsing around to find the link. This may have been due to the position, styling and labeling of the links. Overall, these factors do not undermine the potential of topic- and list-based strategies, but indicate important details about the experimental instruments and page design that might have skewed the actual navigation behavior.

Topic-based and List-based Back Reduce Distraction

Results of our observation of users' physical behavior suggest that both the topic- and list-based back navigations help to reduce distraction from a simple walking task. Our findings suggest that these two navigation strategies better support eyes-free aural experiences. They involve less user attention compared with traditional back navigation, which requires users to continuously interact with a page and click on the back button to traverse back to each and every page.

Enhancement in Navigation Experience

For both advanced navigation strategies, the ratings of navigation experience were significantly higher than the control group, particularly on two questionnaire items: "the website provided enough guidance for me to navigate through the content" and "it was easy for me to return to previous pages." The former item implies that users considered both navigation strategies as *guidance* to the content. The latter confirms that topic- and list-based back can make back navigation much easier than traditional back. This finding puts in better perspective the lack of transparent mental model as previously discussed. The fact that most users were not able to fully articulate the basic mechanisms governing the navigation strategies, did not prevent them from consistently acknowledging their ultimate utility for navigating complex architectures.

Reducing Perceived Cognitive Load

Our findings show that both advanced navigation strategies reduced cognitive load especially on two fronts: "physical demand" and "temporal demand." This evidence indicates that participants felt less rushed and needed less physical operation in accomplishing the browsing tasks. Moreover, list-based back resulted in significantly lower rates in user's frustration. Collectively, this evidence suggests that the second half of H1 (topic-based back yields a better navigation experience and reduces perceived cognitive load) and, similarly, H2, are also confirmed.

Validity and Limitations of the Study

Internal Validity

We used several strategies to maximize internal validity. First, we adopted a within-subject design in which both performance data *and* self-reported, subjective experiences were collected. Second, we captured not only the standard task performance and experience indicators, but also a number of contextual measures (stop signs missed, step-outs, and unnecessary stops) that are representative of critical factors in mobile scenarios. Third, to mitigate the learning effect within subjects, we carried out a consistent training session with each participant before the experiment, so that the participants' knowledge about the website could reach a common threshold of familiarity with the site. Finally, the order of the advanced navigation conditions was also counterbalanced across participants.

Even though traditional back was always presented before the advanced navigation, we argue that this potential learning effect is minimal. In fact, there was no double exposure to the same parts of the application because the actual tasks assigned were equivalent only in terms of types of navigation path, but differed in terms of traversed pages. Consequently, the only thing participants were familiar with before entering the advanced condition was the site structure. A limit of our experimental design is the fact that the walking path was exactly the same across conditions. The habituation to the path, however, is partially mitigated by the counterbalancing of the advanced strategies and the differences in the tasks. Also, the initial training and the simplicity of the path left little to learn after the first walk.

External Validity

The purpose of topic- and list-based navigation strategies is not to replace the existing back links of a given web application, but to enable aural users to perform navigation at a higher, conceptual level (which is at the same time more natural and efficient) on top of existing navigation structures. As such, topic- and list-based readily complement existing research on strategies for aural page structuring [21], by operating at the level of the information architecture of a site. Designers who work on large-scale, engineered web architectures (e.g., thousands of pages) will easily recognize a mapping between the information architecture of their websites and the proposed navigation semantics. In fact, most of the proposed design concepts (topics, parts of a topic, list pages) are constantly underlying the rapidly changing patterns of most complex, content-intensive web applications [29]. These aural navigation commands can be applied to all known types of information architectures, with one exception. Websites with simply structured content units (e.g., a one page description of a product) would not benefit from topic-based back, which would assume the availability of multiple pages for a topic. Similarly, sites with few list pages would not benefit much by the "shortcuts" of list-based back. As we did with GSM, topics and lists can be conceptually identified at design time (or reverse-engineered from existing sites) and marked on the information architecture. The user's history session can then be tracked on the server; on the client side, topic- and list-back links (or gesture listeners) are dynamically generated based on the simple navigation rules of the two patterns, and included in the page templates.

RELATED WORK

Research on supporting eyes-free, aural experiences is gaining momentum in combination with the pervasive presence of advanced mobile devices. As a most recent example, the Apple iPhone 4S SIRI personal assistant promotes a highly semi-aural paradigm, where aural output is the primary modality, complementary to the visual display.

Brewster et al. [7] argue that when users focus their visual attention on visually-demanding interfaces, they face difficulty navigating their environments. Borden [4] also emphasizes that visual interfaces often need most of the cognitive resources of the user in order to complete simple tasks, such as clicking a button. Hence, visual interfaces may be highly distracting when used in parallel to other visual activities (such as walking, jogging or driving) since both draw from the same pool of limited cognitive resources [33].

From this perspective, there has been extensive work that explored ways to use audio to replace visual feedback in mobile scenarios [30, 13] and in content-rich web applications in general [18, 32]. For instance, BlindSight [19] enables users to access their contact lists or digital calendars using audio cues, thus without being forced to look at the mobile device at all times. In this context, topic-based back, for example, can support re-finding of appropriate "conceptual" entities (rather than actions or steps) in the array of personal information. One could easily find the "next event" scheduled, or the "last meeting" attended. In a similar vein, Ec(h)o [31] is an example of advanced "audio guide" that enables museum visitors to focus their attention to the exhibited objects, while listening to complementary explanations. In these scenarios, topic- and list-based back can facilitate the aural navigation in the collection by jumping directly to the previously visited work of art or area (set of works) of the collection.

Past works on web structures have demonstrated the importance of back navigation [9, 10]. For example, by analyzing log files, Catledge and Pitkow found that back navigation accounts for 41% of all the web interaction activities [9]. They also found that a user's navigation history usually shows "a spoke and hub structure" [9], which is analog to accessing topics via a list. Capitalizing on the characteristics of web navigation history, Milic-Frayling et al. tried to substantially enhance back navigation experience by visualizing the types and the structure of a user's navigation trail [22, 23]. They introduce a browser feature called "SmartBack" [23], which can automatically detect the dynamic "hubs" of in-depth web browsing. In a complementary perspective, Cui et al. specifically propose that "navigation history" should be designed by prioritizing the key content that a user has visited and skip "less meaningful pages" [11]. Topic-based back embraces this general notion and formalizes it into a reusable and systematic design approach for the aural web.

CONCLUSIONS AND FUTURE WORK

The novel contribution of this research is to introduce and evaluate two back navigation patterns that can significantly improve the aural browsing of large websites in mobile scenarios. Our work is a fundamental step in addressing the structural, conceptual transformations that are much needed when moving from the visual to the aural web. Whereas current sites do offer mechanisms to navigate across sets of pages (e.g., menus, tabs, breadcrumbs), these common visual patterns need to be rethought for auditory navigation. To address this problem, we introduced two higher-level, conceptual back shortcuts suitable for aural browsing. Topic-based back leverages the notion of topic to quickly shortcut back across several collections (and therefore skipping tabs, breadcrumbs and menus). List-based back leverages list pages to directly navigate up to lists across several navigation trails. We demonstrated and empirically evaluated the potential of topic- and list-based back to enhance aural back browsing while on-the-go. Our findings suggest that the principles guiding those strategies result in significant improvements in navigation effectiveness and efficiency. In a parallel research effort, we are evaluating topic- and list-based back to support aural browsing for blind users of screen readers, in close collaboration with the Indiana School for the Blind. Our rationale is that the same aural interaction strategies used to navigate mobile websites might *also* enhance traditional web browsing when looking at the screen is not an option.

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APPENDIX A: Aural Navigation Tasks*

Task A: Navigating Back to a Visited Topic

[Access a topic instance and browse its details] Small changes in your energy consumption at home can make a great difference on your electric bill over time. Find a list with all the energy saving tips that you can complete in 10 minutes or less. From this list, find out how to save energy with your computer and listen to the specific directions on how to do so.

[Navigate to a related topic] While thinking to renew your computer equipment, look for a ViewSonic monitor and find out how much it costs. Check to see if there are any rebates for the monitor, and if so, determine how much money you would get back.

[Back to visited topic] Go back to keep on listening to further instructions on how to save energy with your computer.

Task B: Navigating Back to a Visited List

[Access a topic instance and browse its details] The Winter season is coming and you want to take proper precautions on how to save on your gas bill. Find a list with all the saving tips related to all areas of the house. From this list, find out more about re-sealing windows and doors and then read all the directions on how to do so.

[Navigate to a related topic] While thinking about doors and windows, look for a door draft stopper kit. First, check the reviews of this item, then see if there is a rebate for it, and how you can get it.

[Back to visited list] Choose another green tip related to Spring.

**** Tasks with equivalent structure were assigned in Stages 1-4.***

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