# Non-Visual Menu Navigation: the Effect of an Audio-Tactile Display

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**We present a preliminary study examining non-visual menu navigation in terms of task completion times and cognitive workload. We asked 12 participants to locate items on menus presented using visual, audio-only and audio-tactile displays on a touch screen mobile device and found that users were significantly slower in locating an item on a menu when using an audio-tactile menu display. This difference in performance was not reflected in the users' subjective workload assessments. We discuss the implications of these findings in terms of cross-modal display and the design of menu navigation gestures on touch screen devices.**

*Touch screens, menu navigation, tactile feedback, auditory display, cross-modal interaction, cognitive load*

## 1. INTRODUCTION

Touch screen technology has gained increasing popularity with both users and manufacturers and bring new opportunities and challenges for supporting users who need non-visual access, whether this is due to their context of interaction or to perceptual impairments. For instance, having done away with the physical keyboard, soft buttons, icons and keyboards on touch screen devices often need to be accompanied by appropriate feedback using visual, auditory or tactile cues in order to enhance user performance and experience (Brewster *et al* 2007). But despite significant progress in accessible technology, non-visual interaction with touch screen technology remains problematic (Brady *et al* 2013). More thorough studies are thus still needed in order to investigate the effectiveness of using multimodal displays to improve interaction with this kind of technology. This paper focuses on examining non-visual interaction with menus. Menus are a strong component of the dominant interaction metaphors used on most computing devices and remain a popular means for organising information on both desktop computers and mobile devices. We are interested in investigating the effects that different modalities have on users when performing non-visual menu navigation and present a preliminary study that examines this question by contrasting menu navigation on a touch screen mobile device.

## 2. RELATED WORK

A number of studies have examined how to support non-visual menu navigation that could benefit both sighted and visually impaired users. For instance, Kane *et al* (2011) examined the use of gestures on touch screen mobile devices and suggested a number of guidelines for making mobile devices more accessible. Amar *et al* (2003) developed the Mobile ADVICE system, which uses a physical scroll wheel combined with auditory and tactile feedback to navigate menus on handheld mobile devices, while Li *et al* (2008)'s BlindSight system relies on the phone's physical keypad to support non-visual menu navigation during phone conversations. Zhao *et al* (2007) developed EarPod, which uses a circular touchpad together with auditory feedback to support non-visual interaction with hierarchical menus, and found that it outperforms visual menus after training. These approaches currently require bespoke hardware to function and are therefore not readily available to the majority of users. Sànchez *et al* (2007) developed desktop and mobile applications that rely on directional gestures to support visually impaired users when traveling in the subway, and Kane *et al* (2008) developed Slide Rule, which allows for multi-touch gestures when interacting with mobile devices.

The inclusion of haptic and tactile feedback in mobile interaction is often associated with improved


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usability and performance. For instance, Pielot *et al* (2012) developed PocketMenu to support eyes-free in-pocket use of a handheld touch screen device and found that adding tactile feedback allows for faster interaction, while Brewster *et al* (2007) found that tactile feedback improves text entry on a touch-screen keyboard in both static and mobile contexts of use. Koskinen *et al* (2008) showed that tactile feedback improves the usability of virtual buttons on touch screen widgets, and Brewster *et al* (2004) suggest the use of structured Tactons - abstract messages that can be used to communicate information - as a means to improve accessibility of mobile devices for blind users.

## 3. STUDY

We aimed to conduct an initial investigation to examine users' performance on non-visual menu navigation tasks when using a touch screen mobile device. We recruited 12 participants, all were students from the authors' university with technical background in Computer Science and Electronic Engineering. All participants were experienced in using touch screen mobile devices but had no experience in non-visual interaction with these devices. We used a within-subjects design with participants navigating a menu using a visual display (Visual control condition), an audio-only display (Audio-only condition) and an audio-tactile display (Audio-Tactile condition) in a counterbalanced order. The aim was to use the Visual condition as a baseline of performance that we could use to contrast and compare the non-visual interaction.

### 3.1. Procedure

Each condition was preceded by a training phase where the experimenter assisted the participants as they completed similar tasks to the ones used in the testing phase. Participants were allowed to look at the mobile screen as they navigated through the menus. This was not allowed during the testing phase in the Audio-only and audio-tactile condition. Training lasted for 15 minutes and included two sample tasks. In the testing phase, participants were asked to locate menu items from a given menu structure in each condition. Items that needed to be retrieved were located in the 4th depth level of the menus. An example of a task instruction is: "Please find the attribute 'Exotic' of the class Fruit". The navigation path to retrieve this item is: "Diagram > Classes > Fruit > Attributes > Exotic". As is typical with mobile devices, each screen displays a single level of the menu structure at a time (see Figure 1). We administered a NASA Task Load Index questionnaire after each condition.

### 3.2. Apparatus

We used a Samsung Galaxy Note GT-N7000 touch screen mobile device running Android version 4.0.4. Navigating a menu on this device is done using a mixture of touch-based gestures and tapping. To navigate a list of items a user places one finger on the screen and moves it up or down, we refer to this action as *swiping*. To select an item, the user must tap the screen at the location of that particular item.

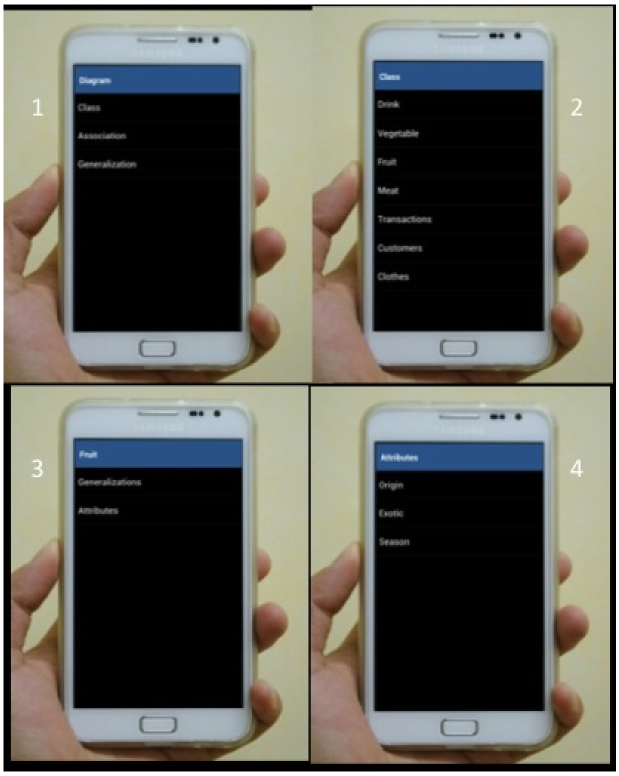


***Figure 1:*** *Example of four levels structure of menus on the mobile device.*

We used the Google TTS Engine version 4.0.4 to speak the labels of the items in the Audio-only and Audio-Tactile conditions with a speech rate of 0.3 words per second (WPS). The audio was presented through the device's built-in speakers. Additionally, we displayed a single vibrotactile pulse in the Audio-Tactile condition whenever the user's finger encountered a menu item at 200 milliseconds per pulse. We instructed the participants to hold the mobile device out of sight under a table while seated during the Audio-only and Audio-Tactile conditions. Each participant held the device with their non-dominant hand and used their dominant hand to navigate the menus.

### 3.3. Measurements

We calculated the average time it took the participants to locate a menu item as a dependent variable and captured users' subjective assessment of the cognitive workload. All interactions were timestamped and logged.

### 3.4. Results

A One-Way ANOVA test showed a significant main effect in the average task completion times ($F(2,22)=6.75$, $p<.05$). A Tukey HSD post-hoc test showed a significant main effect between the Visual ($M=42$, $SD=29.81$) and the Audio-Tactile ($M=114.75$, $SD= 93.08$) conditions ($p<.05$), and between the Audio-only ($M=86.16$, $SD=25.94$) and the Audio-Tactile conditions ($p<.05$). The differences between the Visual and Audio-only conditions were not significant (Figure 2). Participants thus spent significantly longer times to locate items when menus were presented using an audio-tactile display.

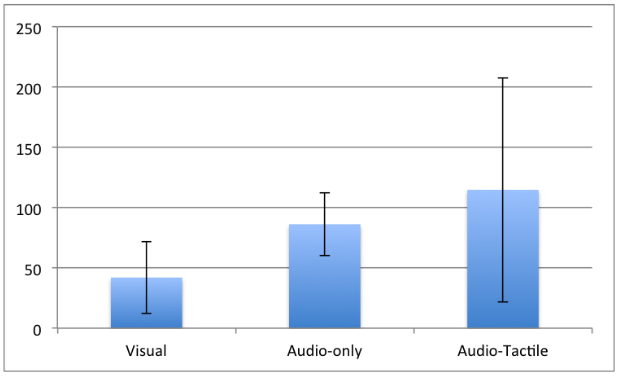


***Figure 2:*** *Average task completion times (seconds), error bars show SD*

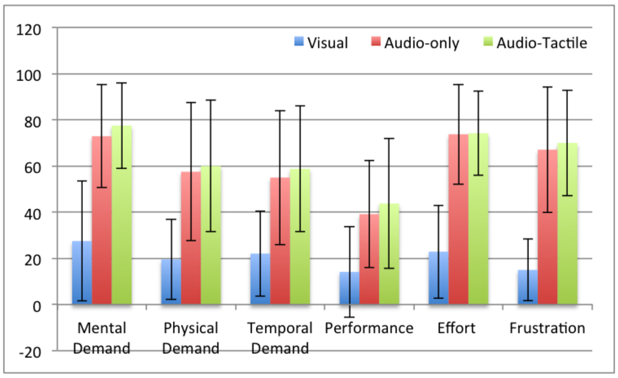


***Figure 3:*** *NASA TLX results, error bars show SD.*

A detailed analysis of the NASA TLX questionnaires showed that the overall workload was significantly higher in the Audio-only and Audio-Tactile conditions than in the Visual condition ($F(2,22)=33.39$, $p<.0001$). Differences between workloads in the Audio-only and Audio-Tactile conditions were not statistically significant (Figure 3).

Given the above results, we conducted further analysis to investigate how participants were slower in the Audio-Tactile condition. As described above, navigating menus on the touch screen mobile device used involves executing two actions: swiping and tapping. Since tapping is an instantaneous action, we decided to extract swiping times from the interaction logs that we captured in order to calculate and compare average swiping times across conditions. The results are shown in Figure 4.

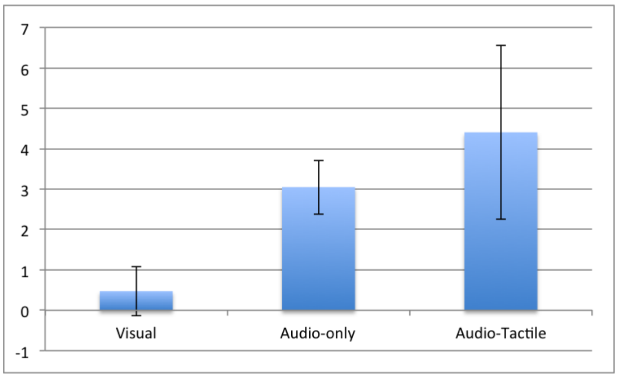


***Figure 4:*** *Average times (seconds) for swiping, error bars show SD.*

A One-Way ANOVA test showed a significant main effect between the average swiping times ($F(2,22)=29.4$, $p<.0001$). A Tukey HSD post-hoc test showed significant main effect when comparing the Visual ($M=0.47$, $SD=0.6$) and the Audio-only ($M=3.04$, $SD=0.66$) conditions ($p<.01$), the Visual and Audio-Tactile ($M=4.4$, $SD=2.15$) conditions ($p<.01$), and the Audio-only and Audio-Tactile conditions ($p<.01$). Participants average swiping times were thus slowest when menus were presented using an audio-tactile display.

## 4. DISCUSSION

The goal of the presented study was to contrast different modalities for presenting menus on a mobile touch screen device and examine the effects that these have on users when performing non-visual menu navigation tasks. Two main questions were addressed. First, how does performance on audio-only and audio-tactile menu navigation tasks compare to visual menu navigation. Secondly, what effect does the addition of tactile feedback have on users' performance when using a non-visual display. These effects were examined in terms of task completion times and subjective workload assessment.

With regards to the first question, participants in our study were significantly slower when navigating non-visual menus. These results were anticipated. Our participants were all sighted, computer literate and had no prior experience interacting with computing devices through a non-visual interface. This could also explain why they found the workload in non-visual conditions much more demanding. Clearly, participants's performance was biased towards the visual modality, but as stated above, the aim behind including a visual condition was to provide a baseline against which performance using audio-only and audio-tactile displays can be contrasted.

In relation to the second question, The addition of tactile feedback seems to have slowed down performance. Our results contrast findings reported by similar studies in which adding vibro-tactile feedback was reported to improve user performance in terms on completion times (e.g. Brewster *et al* 2007; Pielot *et al* 2012). For example, Pielot *et al* (2012) found that users controlling an MP3 player using their PocketMenu system, which included vibro-tactile feedback, do so much more efficiently than when using Apple's VoiceOver screen reader in terms of completion times, selection errors and subjective usability. Our results contrast theirs despite similarities in the menu navigation styles we used and the one developed by Pielot *et al* (2012). To browse a menu non-visually, the user moves a selection cursor through a list of items and receives audio or audio-tactile feedback. In our system, the user moves the cursor by swiping their finger across the device's screen to navigate the list, starting from the top with menu items laid out vertically, one menu item at a time. A short tactile pulse is then displayed to indicate that the finger has crossed over to a new item. While the audio feedback that describes each menu item can be interrupted when moving to the next item, it is possible that the addition of the tactile feedback led our participants to wait for the full item labels to be uttered before they moved on to the next item, which would have contributed to increasing the overall completion times. This is supported by the results we obtained when comparing the average swiping time across conditions.

The major issue that this finding raises is therefore the question of when it is appropriate to actually use visual, auditory, and/or tactile feedback. Clearly, these display techniques cannot all be used in identical situations and contexts without impacting performance. It is therefore important that designers consider potential cross-modal interaction effects when representing information through more than one modality simultaneously. In this case, a redesign of the tactile feedback to allow for interruption (as per the audio display) could allow for faster interaction. Additionally, the issue might also lie within the implementation of the swiping action itself, which might not be ideal for speedy performance. An alternative might be to allow for the swiping action to be initiated at any point on the touch screen rather than only at the top of the list – which would be similar to the approach used in VoiceOver where navigation between adjacent on screen objects can be performed by swiping gestures irrespective of where those gestures are performed on the touch screen – and to provide a quick overview of such a list, for example by exploiting the use of spearcons (Walker *et al* 2006). While this might impact orientation within the menu, it could allow for faster exploration and browsing time. Further studies that contrast different implementation of finger gestures for menu navigation could highlight how their design can be improved.

Interestingly, the effect that we observed on completion times was not reflected in our participants' subjective assessment of cognitive workload as measured by NASA TLX. Our participants were thus unaware that the tactile feedback had slowed down their performance. We note here the usefulness of capturing cognitive workload as part of assessing the usability of interaction on a mobile device. A recent literature review on usability assessment of mobile applications showed that cognitive load is in fact often overlooked by common mobile usability models Harrison *et al* (2013). In our case, capturing this dimension has revealed interesting dynamics between the objective and subjective measures that we obtained as part of our assessment. Analysing this data seems particularly important in the context of mobile use, where users are likely to have a variety of sensory inputs competing for cognitive capacity; for instance, interacting with their device on the move or while multitasking.

There are a number of limitations to our findings, however. First, it is important, to note the high variability in the results we obtained as indicated by the high standard deviation recorded in the Audio-Tactile condition, which can be attributed to the limited number of participants and trials used in each condition. More thorough studies to follow up on this preliminary study are needed to confirm the results across a wider sample. The results are also specific to our implementation of tactile feedback and are therefore too preliminary to be generalised to the inherent properties of cutaneous sensory perception and tactile as a feedback modality. Secondly, we used a fixed menu complexity (70 items organised over 4 levels). While this might be a usual level of complexity for mobile applications, it does not reflect the variety of menu structures found on these devices. It is likely that completion times change, and hence the observed effect of tactile feedback, when dealing with more or less complex menus that are structured differently to our apparatus.

Additionally, the way we imposed non-visual interaction (holding the device out of sight under a table) might also not reflect real world "natural" use of mobile devices. A more realistic approach might involve asking users to navigate menus when holding the device in their pockets, as was used in (Pielot *et al* 2012), or simply blindfolding the participants, thus allowing them to hold the device in a more comfortable position. There are exceptions to this, for instance, students have been observed in classrooms texting under their desks (O'Brien 2009), which means that our experimental setting was not entirely unrepresentative. Finally, as highlighted above, there is an inherent limitation in recruiting sighted participants to perform non-visual tasks, which will not reflect the experience of visually impaired users. Nonetheless, we believe that support for non-visual interaction is relevant to both sighted and visually-impaired users, and we plan to conduct future studies that involve both populations.

## 5. CONCLUSION

We presented a preliminary study that examined menu navigation on a mobile touch screen device. Our initial results showed that the addition of tactile feedback to a non-visual display of a menu on a mobile device increases task completion times and that this is not reflected in users' subjective assessment of cognitive workload. This result contrasts those previously reported by similar studies. While limited to the particular implementation of the system we used in this study, further investigations into the generalisability of this finding may have significant implications for the understanding of multimodal and cross-modal interaction design. The use of a subjective measure of cognitive workload has also helped in revealing interesting dynamics within the captured data.

## 6. ACKNOWLEDGEMENT

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