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A Study of User Perception, Interface Performance, and Actual Usage of Mobile Pedestrian Navigation Aides

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The proliferation of pedestrian navigation tools has made it challenging for users to avoid being confused and overwhelmed by the choices. Studies comparing mobile pedestrian navigation aides have generally based conclusions on either survey results from separate trials of exclusive interface usage or on performance of the interfaces as judged by the speed with which users are able to complete wayfinding tasks. However, it is not clear if users would mirror their individual trials or find a more strategic mixed-mode approach to using the tools at their disposal when given an option to choose from a set of tools. It is also unclear if users actually care about performance when choosing a navigation tool. We conducted a study to compare actual usage of navigation tools against user perception of the tools and performance with the tools in a series of wayfinding tasks. Results indicate that independent surveys can align well with extreme cases while performance may not actually be a good indicator of usage preferences.

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INTRODUCTION

The number of pedestrian navigational tools on mobile devices has grown tremendously over the past several years fueled, in part, by the increasing computational power of mobile devices as well as by the integration of positional sensors (magnetic, GPS, inertial). However, it is not clear what sort of navigational tool would be most appealing and yield the best benefits to pedestrians. Comparisons of such tools have generally been based upon time-on-task performance but such efficiency measures may not be indicative of what users truly prefer. Usability surveys, often completed after an exclusive use of a particular interface, may also fail to reflect what users will actually choose when given a set of tools. Studies that offer multiple options where users can switch, at will, between tools may be susceptible to a form of loss aversion that favors the status quo because the loss of extending known gains from an existing interface is seen as having a larger negative effect than the potential unknown gain of a new state. Put another way, a user may perceive it to be easier to stay with a system currently in use than to pro-actively reject it in favor of another tool. To alleviate this concern in the present study, we employed a time-out mechanism that forces a user to select, from a menu of navigational tools, an interface after every twenty seconds.

By adopting such a strategy, we may be better able to glean what users would actually do rather than base conclusions on what users say they would like to do when presented with multiple options. This is useful because numerous studies have compared mobile navigation tools and, when users are asked, most tend to state a preference for interfaces that offers a combination of all tools rather than a preference for more familiar tools over new tools or vice-versa. For example, in studies comparing 3D maps against more standard 2D maps, despite problems encountered using unfamiliar 3D interfaces, users generally express interest in interfaces that offer both modes as options (Rakkolainen et al., 2000; Vainio et al., 2002; Kulju et al., 2002). Similarly, in a study comparing standard 2D maps against navigation tools using photographic landmarks, Hile et al., allowed participants the option of switching between interfaces and encouraged them to switch between modes to get a better sense of how the interfaces differed. It was not clear, however, if this resulted in a balanced or strategic use of the tools and, while nearly all participants confirmed that the landmark mode was useful, they qualified their willingness to use it again only if there were an accompanying map mode (Hile et al., 2008).

Because the most common and familiar navigational tool is the standard cartographic map, virtually all comparative studies include a version of this baseline navigation tool. One in three people have expressed difficulties in using standard cartographic maps largely because of the mental rotation required to align the two-dimensional representation with the three-dimensional surrounding of the real world (Street et al., 1985; Board, 1978). Using integrated compasses embedded within a mobile device, Forward-up maps have helped to ease the challenges of mental rotation by continually keeping the map on a digital device aligned with the direction the device is pointed. Studies have found this greatly improves navigational performance when compared against North-up maps where the map itself is always aligned so that geographic north is pointed towards the top of the map (Hermann et al., 2003; Seager and Fraser, 2007).

Reducing the difficulties further, augmented reality (AR) not only aligns lateral turns, like Forward-up maps, but also eliminates the need to correspond symbolic graphical representations on maps to real world landmarks by overlaying visual cues on top of a direct view of the surrounding environment. However, in a study where AR, North-up maps, and audio turn-by-turn directions were used separately and exclusively in urban navigation tasks, AR received the lowest average user experience ratings and yielded longest average task completion times (Rehrl et al., 2011).

Adding the possibility of choice between interfaces, Dünser et al., designed an experiment that counter-balanced three routes and three interfaces, using North-up map exclusively on one route, AR exclusively on a second route, and a combination mode on a third route where both interfaces were available for the one navigation task. In this combination mode, participants had a button they could actuate when an interface change was desired. While participants expressed a preference for the combination mode in post-test interviews, the combination mode yielded the least efficient performance in terms of task completion time (Dünser et al., 2012). It was not clear if the participants were continually cognizant of the option to switch modes so as to best exercise the possibility of switching interfaces effectively and strategically.

In order to assess the utility of pedestrian navigational tools that are available from a selection of possibilities so that we may better understand how users actually employ the tools in the field, we created an environment where the user is continually made aware of the choices available. In this context, the user was free to choose whichever tool they deemed most preferable at any given time.

METHOD

Participants

Thirty participants (11 female) completed the study in exchange for a pair of movie passes. They were told to expect substantial outdoor walking in an urban environment for the study, which lasted between 1.5 to 2 hours. Participants ranged in age between 19 and 42 years (M = 27.3 years, SD = 6.18).

Technology

An iPhone application was implemented that provided users with five forms of mobile navigational aides. The aides were chosen from dozens of possibilities available in the market and from research prototypes so as to provide a representative sample and broad comparative base of different navigational interface approaches:

- North-up map – standard cartographic map where north was always aligned with the top of the map and displaying the user location and the destination (Figure 1a);
- Forward-up map – standard cartographic map where the top of the map was always aligned with the direction the device pointed and displaying the user location and the destination (Figure 1b);
- Linear Compass – ruler-like linear strip that subtended a 90 degree angle and which indicated the position of the destination if it was within the subtended angle or, the direction to turn in order to bring the destination into view (Figure 1c);
- Augmented Reality (AR) – video feed of real world through the device camera with computer generated graphics overlaid, as a three-dimensional cube, in the position of the destination (Figure 1d); and
- Radar – traditional radar metaphor showing the user at the center and the destination relative to the user within a circular area using a logarithmic scale radially to maintain its visibility regardless of distance (Figure 1e).

The distance to the destination and GPS accuracy were displayed in each of the interfaces.

When initially presented to the user, the application displayed a menu with buttons for each of the five interfaces described. Whichever one the user chose was invoked and interactive for a maximum of 20 seconds, at which point the interface was removed and the menu of interfaces was displayed again.

Figure 1. The five navigational tools.

The user may choose not to use any of the interfaces or may select one of the menu items—including the previously used interface—in order to utilize one of the navigational tools for another 20 seconds. If the user wished to switch interfaces before 20 seconds had transpired within the current interface, a button that returned to the menu was shown in each of the interfaces. The button enabled the participant to abort out of the interface before the timeout. Due to the disruptive potential of forced choice, we focused on its effect in pilot tests but received no negative feedback.

Procedure

After a brief introduction and a pre-test questionnaire, each participant underwent a training phase. The training phase used a modified form of the software technology where the timeout is disabled and only one interface was available at a time. The training path was approximately 500 meters long and was divided into five segment pairs, each of which corresponded to one of the five interfaces. The participant was shown how to use the interface and then used it to navigate to the destination. When the participant was within 15 meters of the destination the iPhone vibrated and displayed an alert indicating that the destination had been successfully reached. The relatively large range of 15 meters was chosen after some pilot tests revealed potentially large GPS inaccuracies in the neighborhood. After completing the first segment of the segment pair, the user continued to the second destination with the same interface. Upon arrival at the second destination for the interface, in keeping with similar studies (e.g., Rehrl et al., 2011), the participant completed a usability questionnaire and a NASA TLX survey, a subjective workload rating procedure based upon mental, physical, and other perceived user demands. This was repeated four more times, once for each of the remaining interfaces.

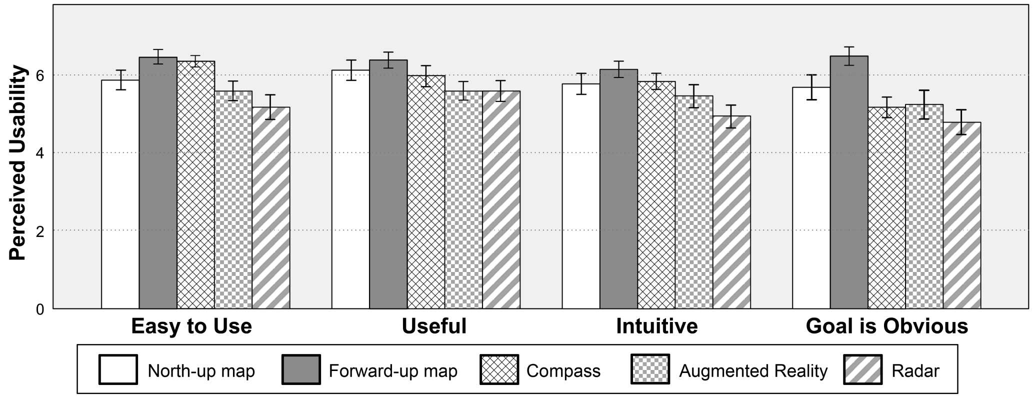

Figure 2. Perceived usability results

A short testing phase followed so that the participant could have the opportunity to become familiar with the imposed time limit and the navigational tool selection menu. The testing path was a short distance away from the end of the training phase and was approximately 200 meters in length. It included two destination points and two turns. The participant was encouraged to try the various interfaces as well as experience how the system replaced the interface with a menu when it timed out after twenty seconds.

The experiment proper began at the location where the testing trial ended and, after ensuring the participant was comfortable with the application--they were asked if they would like more testing time; none of the participant requested it--the participant began by selecting an interface to navigate to the first of the seven destinations of the experimental trial. Each segment ranged from approximately 75 meters to approximately 300 meters although participants who deviated from the optimal path were not corrected and so could potentially wander much further afield. At each destination, the participant completed a short questionnaire and, after the last destination, the participant was given a post-test questionnaire.

RESULTS

During the training phase, the participants were asked to rate perceived usability (ease-of-use, usefulness, intuitiveness, destination was obvious) and workload demands (mental, physical, time, effort, frustration) for each of the interfaces, scored on 7-point and 100-point scales, respectively.

Perceived Usability

Figures 2 shows the results of the perceived usability questionnaire. Forward-up map was rated highest in all areas while the Radar interface was rated lowest in all areas. Analyses of variance were applied to the results and significant effects based upon the type of user interface were found for ease-of-use, $F(4, 145) = 3.41$, $p = .011$; intuitiveness of the interface, $F(4, 145) = 4.40$, $p = .002$; and the ease with which a goal can be seen from the interface, $F(4, 145) = 5.12$, $p = .001$. No significant differences were found between the interfaces for perceived usefulness.

Post hoc Bonferroni analyses applied to the differences indicated that the Compass interface ($M = 6.37$, $SD = .81$) as well as the Forward-up map ($M = 6.43$, $SD = .97$) were perceived to be significantly easier to use than the Radar interface ($M = 5.00$, $SD = 1.93$). The Compass interface ($M = 5.80$, $SD = 1.063$) as well as the Forward-up map ($M = 6.14$, $SD = 1.093$) and North-up map ($M = 5.80$, $SD = 1.42$) were all perceived to be significantly more intuitive to use than the Radar interface ($M = 4.93$, $SD = 1.53$). Both the Compass interface ($M = 5.10$, $SD = 1.45$) and the Radar interface ($M = 4.79$, $SD = 1.72$) were perceived to be significantly less obvious in showing the goal than the Forward-up map ($M = 6.48$, $SD = 1.21$).

Perceived workload demand

Figure 3 shows the scores for the perceived workload demand based upon an average of the NASA-TLX items for each person for each tool. High levels of internal consistency ($\alpha > .890$) were found for all the interfaces except the Radar ($\alpha = .594$).

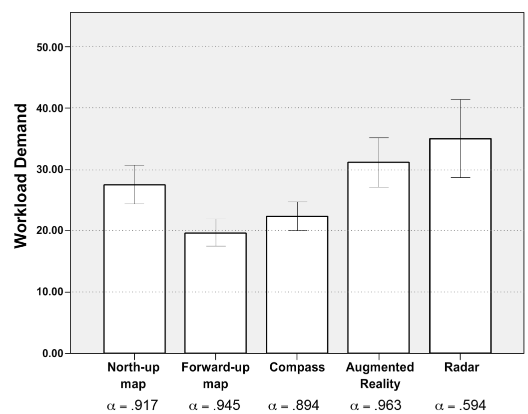

Figure 3. Workload demand with Cronbach α values

A repeated-measure ANOVA with a Greenhouse-Geisser correction determined that there were statistically different perceived workloads depending on the interface used, $F(2.965, 83.013) = 6.858$, $p < .001$. Post hoc tests using the Bonferroni correction indicated that the Compass interface ($M = 22.414$, $SD = 2.354$) and Forward-up map ($M = 19.724$, $SD = 2.142$) had significantly lower perceived workload demand than both AR ($M = 31.172$, $SD = 4.110$) and the Radar interface ($M = 30.966$, $SD = 3.756$).

Actual usage time

Because participants generally referenced the device periodically rather than monitor it continuously, the automatic timeout removing the interface may go unnoticed. We chose to interpret the time where the device did not display any navigation tool as an indication that the user was still relying upon the most recent interface. In other words, the information given by the most recent navigation interface was still being actively used without a need for further information. Consequently, we combine the time the interface is actively displayed (active time) with the time the menu is displayed immediately after the timeout has occurred for the interface (passive time) and used this combined time for our analysis in usage time and traversal speed.

Figure 4 shows the percentage of time each interface was used over the seven segments. Collapsed across users, it can be seen that the Forward-up map starts with the greatest percent of usage in the first segment (*M* = 37.7%, *SD* = 5.3%) while Radar starts with the least usage (*M* = 8.3%, *SD* = 2.4%). Forward-up map usage generally increased over the segments, reaching a maximum at the last segment (*M* = 59.2%, *SD* = 5.8%). Usage of other interfaces all drop, with AR dropping most substantially (from *M* =18.1%*, SD* = 4.1% to *M* = 6.5%, *SD* = 1.9%).

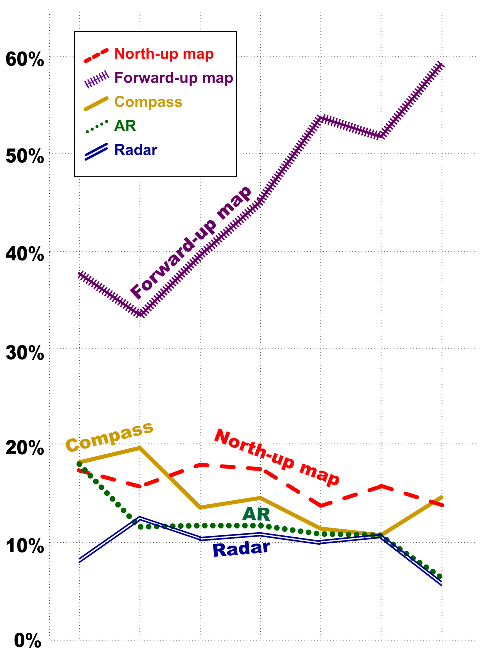

Figure 4. Actual usage time over segments.

Average traversal speed

Although, with only a few exceptions, traffic conditions did not interfere with the participants, stops were sometimes made in order to interpret the navigation tools. The stops were therefore considered a consequence of the tool itself and part of the speed calculation, which was determined by dividing the total distance traversed (in meters) by the time transpired (in seconds) for each interface. The average speed was then collapsed over the seven segments and the thirty participants. These are shown in Figure 5. An ANOVA showed that the interface used had a significant effect on the traversal speed, $F(4,128) = 3.00$, $p = .021$. A post hoc Bonferroni analysis indicated a significant difference in speed between the Compass (*M* = 1.49 m/s, *SD* = .21) and the AR (*M* = 1.22, *SD* = .49) interfaces.

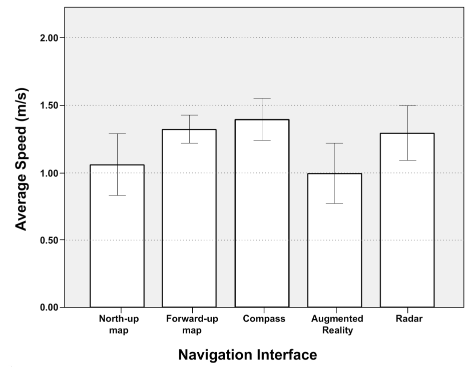

Figure 5. Average speed of interfaces.

DISCUSSION

The findings of the present study suggest that user perception of navigation interfaces judged separately may be closely aligned with actual usage preferences in an environment where the interfaces are offered collectively. Further, it appears that there may be cases where usage preferences are more consistent with self-reported perception than with performance measures.

Although one typical standard for judging a new interface is its time-on-task efficiency, from a user's perspective, performance measurements for such tools may not be the best indicator of how appealing a tool is. For example, despite the compass interface yielding the best average walking speed, its actual usage was relatively low. A possible reason for this is that the compass tool suffices for simple navigation tasks (e.g., straight-line traversal) allowing top speeds to be attained easily while complicated navigation tasks may require more sophisticated tools that are, as a result, associated with slower speeds. Consequently, while the speed measurement is potentially robust and sensible in a mixed-interface environment, the short durations of usage may not properly capture the tool's true utility if no other tools were available. The forward-up map interface, on the other hand, resulted in slightly slower walking speed but was heavily favored in actual usage—to such a disproportionate extent that a closer examination is justified.

The advantages of the forward-up map's directional information over the north-up map's fixed orientation are well known (Hermann, 2003; Seager, 2007). However, if the easing of lateral rotations was the sole benefit, then the AR interface should have fared better since it not only addressed lateral rotations but also eliminated the task of making correspondences between cartographic representations with real world features. One possible explanation is that the correspondence advantages of AR are offset by the disadvantages GPS inaccuracies being magnified. While all the interfaces received the same geographic location data, the effects of the integrity of the data on the tool varied widely. Erratic GPS signal may not be visible in map interfaces where each pixel of the display may represent several meters. The AR interface, in contrast, works on a real-world scale and therefore exhibits signal fluctuations even on a sub-meter scale. The resulting visual jitter may diminish trust in the tool's validity even though the GPS signal is no less valid than what the maps receive. Adjusting and compensating for such signal noise require effort and may lead to user frustration.

Another possible factor is that forward-up maps offer not only more information but also the illusion of more information. It is not clear if the surrounding map-like context of forward-up maps is used as effectively as north-up maps since situation awareness has been observed to decline in users of forward-up maps when compared to users of north-up maps (Smets et al., 2008). This may speak to users focusing on the compass-like directional information of a forward-up map more than the area survey information provided. Despite difficulties many people have using maps, the knowledge that maps have been—and continue to be—trusted and effective tools may make the forward-up map attractive as a comfortably easy-to-use map-like tool, even if the cartographic context is largely ignored.

It should be noted that offering interface choices within a navigational task is necessarily at the expense of measuring the efficiency of particular tools exclusively over uninterrupted sessions. Short bursts of speed may contribute disproportionately to the high performance of certain tools but tools offering occasions of efficiency may still not be chosen very often in a multi-interface environment. Although the training phase supported exclusive tool usage, it was not part of the experiment proper and was not counter-balanced between the participants.

That performance may not be the determining factor in the usage and adoption of a navigation tool is in agreement with the navigation model of Arnig et al., wherein acceptance of a navigational aide is based more upon a causal sequence of navigational user experience rather than on performance (Arnig et al., 2012). Arnig et al., speak of the clarity of information provided leading to trust in a system and the perception of lack of disorientation. The mental rotations required in north-up maps may inhibit information clarity while the sensitivity of the compass and AR interfaces to GPS fluctuations may diminish both trust as well as clarity. The logarithmic scale used in the radar interface may serve to confuse users, as well, since the distortion used to ensure that the destination is always within view was not intuitive. The forward-up map provided clear and (assumed) trust-worthy information which, in accordance with the model of Arnig et al., led to its acceptance, as observed in the increased usage of forward-up maps over the segments.

We expect that, as tracking technologies improve, future research will want to re-visit how non-map navigation tools may compare with map-based tools. In particular, it would be worthwhile to gain insights into how the distinctions between forward-up maps and non-map tools could be exploited to provide practical advantages beyond directional guidance. For example, could the potential for enhancing the surrounding environment with direct visual cues in AR offer greater situation awareness than what is offered in forward-up maps? Such insights can help to expand the realm of possibilities of navigation tools to go beyond the limits of traditional tools that may not fully exploit the potentials of newer technologies. In fact, indications that performance—although easily measured objectively—may not be a strong determinant of user preference as much as perceived usability, may support studies that seek to measure user preference in terms of utility and user choice rather than efficiency (Toomim et al., 2012). In this way, the findings from this study may go beyond the immediate field of pedestrian navigation to support a more general and basic understanding of usage behavior.

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