A HUMAN-CENTRED APPROACH TO THE DESIGN OF IN-VEHICLE INFORMATION SYSTEMS: A CASE STUDY IN USABILITY ASSESSMENT

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ABSTRACT: The potential of IVIS to cause driver distraction highlights the need to ensure that such systems are designed in such a way that driver safety is not compromised. The human-centred design approach has much to offer in this regard. Central to this approach is that interface design is an iterative process, and that information on usability is collected as part of this process thus helping to inform system design. As a case study, the usability of three IVIS display presentation concepts for music selection was compared in each of two phases of design iteration. In Phase 1, data on usability were collected through a cognitive walkthrough approach involving experts. In Phase 2, data were collected as part of an experimental, lab-based study involving potential users. The method was effective in highlighting areas for design improvement and was sufficiently sensitive in differentiating the concepts on the basis of their usability.

1 INTRODUCTION

The increasing pervasiveness of in-vehicle information systems (IVIS) brings to the fore concerns regarding the potential of such technologies to distract drivers unduly from the primary driving task. These concerns are augmented by the increasing complexity of IVIS; the ability to provide increased functionality through developments in technology presents the requirement to provide interfaces that allow users to access those functions. The challenge is to ensure that these interfaces are designed in such a way that interacting with the technology does not affect driving performance to such a degree that safety is compromised. Applying a human-centred design approach to IVIS design has much to offer in this regard.

Human-centred design involves applying knowledge about potential users to create and produce systems that match users' expectations and requirements [1, 2]. A defining feature is that system design is an iterative process, and that incorporating user feedback and assessing systems for their usability is an integral part of this process [2]. The iterative nature of human-centred design means that a system may progress through several phases of refinement before its eventual full-scale manufacture and deployment. At each phase, issues concerning usability can be identified and addressed. In the driving setting, the implication is that a usable IVIS will be less likely to be associated with an adverse effect on driving performance than an IVIS with poor usability.

Usability applies to all aspects of a system with which users might interact [3]. While several, more specific definitions exist, it is agreed that usability is a construct comprising multiple dimensions [4]. As defined by ISO 9241-11 [5], the usability of a system refers to the extent to which the system can be used by

specified users to achieve goals of effectiveness, efficiency, and satisfaction in a given context of use. Effectiveness relates to the accuracy and completeness with which users are able to achieve certain goals through system use. Efficiency concerns the amount of effort that users must invest in order to achieve the level of accuracy and completeness required for achieving their goals. Satisfaction relates to the extent to which users have positive attitudes regarding system use.

A variety of tools and techniques exist to enable and facilitate the systematic collection of information regarding system usability [3, 6]. The choice of techniques and whether the direct or indirect involvement of end users is required will depend on a number of factors, including the stage of the design life-cycle and resource availability. For example, usability inspection techniques involving experts are typically less resource intensive than some other techniques and so, might be more appropriate at the early stages of system design when the system may exist only in the form of a relatively low-fidelity prototype. As the system progresses through the design life-cycle, usability can be assessed by asking representative end users to interact directly with more advanced prototypes of the system in the intended context of use. Depending on resources, such direct involvement could be achieved through field- and/or lab-based experiments, which involve collection of both objective and subjective data. Regardless of the approach, it is generally agreed that no single usability data collection technique will suffice; rather, what is required is data collection through a suite of complementary tools [6].

Against this background, a research project was undertaken to explore and compare the usability of three IVIS display presentation concepts for music selection across two phases of design iteration. The purpose of the current paper is to provide an overview of this process and, in so doing, to investigate the sensitivity of the process for differentiating IVIS concepts on the basis of their usability, and in identifying areas for design improvement. During the first phase, usability was assessed through a cognitive walkthrough approach. In general terms, a cognitive walkthrough is a usability inspection technique, which involves experts evaluating an interface in the context of tasks that representative users would be likely to perform [1, 7]. The focus of the technique is on usability issues pertaining to the goal of effectiveness, although with potential implications for efficiency and satisfaction. The second phase involved potential end users interacting with updated versions of the concepts as part of an experimental, lab-based study. While also performing a surrogate driving task, participants interacted with the concepts to perform a music selection task. Direct insights into system effectiveness, efficiency and satisfaction were obtained through music selection performance data and questionnaires. While driving performance data were also collected as part of this second phase, the focus of the current paper is on the usability component of the study. Information on the effects on driving performance of IVIS interaction is provided in a companion paper at this conference [8].

2 PHASE 1 – COGNITIVE WALKTROUGHS

2.1 Method

Four human factors practitioners from MUARC with expertise in in-vehicle interface design participated in a two hour session during which they performed a cognitive walkthrough of the three IVIS display concepts under study. Sessions were conducted with the experts on an individual basis and were facilitated by a member of the project team.

The concepts were presented as graphical screen mock-ups on a PC with some interactive functionality. The critical difference between the three concepts was the way in which information was presented on the display (see Figure 1).

Each concept was based on a common method for presenting menu information. In Concept A, information was provided through a standard list. In Concept B, the presentation of items was based on the fisheye menu concept. Concept C was based on the cover flow concept, most notably associated with iTunes (Apple Inc.), with album covers arranged alphabetically around a turntable.

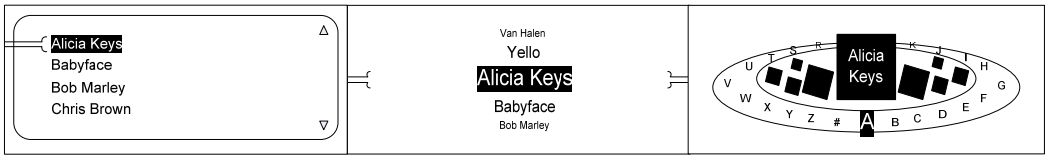

Fig.1. High-level schematic representation of the concepts for music selection studied as part of Phase 1: Concept A (left), Concept B (centre), Concept C (right)

Across concepts, music information was arranged as a hierarchical menu: selectable options became increasingly restricted and refined as users progressed through the menu structure. Scrolling through menu items was achieved by turning the main rotary control, which was adjacent to the display. The lists were circular and so could be scrolled through in either direction, namely up or down. A press of the rotary control served to select the highlighted option and present the list in the next level down the hierarchy. The lowest level was a song list. Other button options were available with each of the concepts and included those that would allow users to filter their music selection by artist, album and song.

In evaluating each concept, the experts' focus was on exploring the ease with which potential users would be able to navigate through the menu structure. To facilitate this process the experts worked through a list of tasks each with a song selection goal (e.g. Find the artist 'Michael Jackson' and play his album 'Thriller'; Skip forward two songs). Issues and potential navigation errors were documented as they arose. Once all sessions had been completed, the experts met as a group to discuss their findings and to agree on a set of suggestions for design improvement and design aspects in need of further testing.

2.2 Results

Presentation of Phase 1 results is framed around the proposed options for design improvement. It is beyond the scope of this paper to present all of the 19 options. Thus, only five key suggestions are discussed here.

Main rotary control functions

For all three design concepts, the rotary control served two functions: turning to scroll through a list at a given level of the menu, and pressing to select the highlighted option in the list. While the scrolling function was clear, experts felt that the select function was not and so may prove problematic for novice users. The experts agreed that the current label ("Menu") was inadequate, and suggested that it be modified to more accurately convey the functions of the rotary control.

Position in a list

The arrows on the right side of the display for Concept A (see Figure 1) were intended to convey to users that the lists are circular and so, can be scrolled in either direction. The experts felt that this purpose was not clear and, moreover, that there was no indication to the user as to the length of the list and how far through a list the user had scrolled. This was particularly true for lists of songs within an album or artist as these lists were not alphabetical. To address these issues, the experts suggested that the arrows be reconfigured into a dynamic status bar, thus providing an indication to the user of where he/she is placed currently within the list of items. It was also suggested that a dynamic status bar be incorporated into the Concept B display to convey list position.

Scrolling direction

Peculiar to Concept B was an issue regarding the effect on list movement of turning the rotary control in a given direction. In the Phase 1 prototype, turning the rotary control clockwise had the effect of scrolling the list upwards. Experts were in disagreement as to whether this was the more intuitive option, with some of the experts arguing that a downwards scroll of the list in response to a clockwise turn of the rotary control was just as plausible. It was concluded that the issue of scrolling direction needed to be considered further in the context of the Phase 2 usability testing, to establish which option is more in line with the expectations of potential users.

Fisheye effect

While experts agreed that Concept B had the potential to rate high on usability, it was also felt that, in its current form, the fisheye illusion had not been fully realised. It was suggested that consideration be given to the best option for improving the look of the display and that this option be implemented for further testing as part of Phase 2.

Use of album art

The Concept C display (see Figure 1) shows album covers arranged alphabetically around a turntable. The user scrolls through the alphabet by turning the rotary control. The list can be scrolled either clockwise or anti-

clockwise. The foremost letter is highlighted and can be selected by pressing the rotary control. This would return a standard listing of the items (as in Concept A) under that particular letter. Although not depicted in Figure 1, when there was more than one album starting with the same letter, all album covers were presented in an overlayed fashion. The experts agreed that the more album covers the more difficult it was to distinguish between the various covers. The effect was to add undue clutter to the display. It was suggested that, to denote that there was more than one album under a particular letter category, only two overlayed album covers be displayed for that letter.

2.3 Discussion

The MUARC experts' suggestions and supporting evidence were discussed with industry-based IVIS designers and engineers. To the extent possible, the concepts and supporting elements (e.g. rotary control) were modified in line with the options for design improvement in preparation for the Phase 2 usability testing.

Of the five suggestions presented above, only the last (use of album art) was not addressed due to time constraints. Thus, there was essentially no change to Concept C. A noteworthy change to Concepts A and B was the inclusion of a dynamic status bar on the right side of the display to signify what portion of a list was shown on screen at a given time and how far through a given list the user had scrolled. A further noteworthy change for Concept B was a new look: items on the screen were hinged at an angle around a focal point on the left side of the display, with items decreasing in size as they moved away from the focal point. The selectable item was that which was centre-most, with horizontal alignment, in the list. A "return/enter" symbol (↵) was also added to the label of the main rotary control.

3 PHASE 2 – USABILITY TESTING

3.1 Method

3.1.1 Participants

Thirty fully licenced car drivers (16 males, 14 females) took part in the study. Participants were aged between 24 and 55 years (M 31.5, SD 8.1) and had held a car driver's licence for at least five years (M 11.5, SD 7.7).

3.1.2 Equipment

Equipment comprised a desktop PC with a 17 inch monitor and a gaming steering wheel (25 cm diameter) with accelerator and brake pedals for implementing a surrogate driving task, and fully interactive prototypes of the music selection concepts described above. The surrogate driving task which was used was the Lane Change Test [9], which consists of a three kilometre, three lane straight section of road. In essence, participants' task is to change lanes as quickly and as decisively as possible when prompted by road-side signs.

The prototypes were housed in a custom-built model of the in-vehicle centre stack of a current model Australian passenger vehicle. The centre stack

included a visual display (14.5 cm x 7.5 cm), rotary control and several push buttons, whose placement relative to the steering wheel in the set-up corresponded with that in the actual vehicle being modelled.

3.1.3 Music Selection Task

Task lists, each consisting of seven items, were constructed. Each item was an instruction directing participants to select a song (e.g. Play the song 'Take a bow' by Madonna). Participants' task was to navigate through the menu structure using the rotary control and available push buttons until the required song had been selected.

Item administration was controlled through DirectRT software (v2006, Empirisoft) and the items were presented via a headset. Item presentation was self-paced (although with a delay): for a given item, once the required song had been selected, the next item instruction was presented following a delay of three seconds. Item completion times were among the data captured automatically by the software. These data were used to calculate the number of items completed per minute for statistical comparison across the three concepts.

3.1.4 Questionnaires

The System Usability Scale (SUS) [10] was used in the current study to provide a global measure of the usability of each of the concepts. It comprises 10 items, each of which consists of a statement and a five point Likert rating scale, which ranges from "strongly disagree" to "strongly agree". Scoring of the SUS yields a total score out of a possible 100. The higher the score, the higher the usability.

An advantage of the SUS is that its output is a single numerical score, which can be compared statistically across systems for evidence of a significant difference. A disadvantage is that it does not offer any insights into the reasons underlying participants' score. For this reason, questionnaires (one specific for each concept and one general) were developed to address the usability goals of effectiveness, efficiency and satisfaction, and to facilitate identification of specific usability barriers. Concept-specific questionnaires comprised open and closed response questions, which were largely the same across concepts to enable systematic comparisons. As part of the general questionnaire, participants ranked the concepts on each of effectiveness, efficiency and satisfaction. In each case, a rank of one was assigned three points, a rank of two was given two points, and a rank of three was assigned one point. The points were then tallied for comparison across the concepts.

3.1.5 Procedure

Each participant took part in a single, two-hour session. Sessions commenced with several training and practice exercises and a baseline trial on the driving task. In turn, the conditions involving the music selection concepts were presented in a counterbalanced order. For each concept, participants first completed the music selection task on its own (baseline). Then, participants completed the music selection task with the driving task (dual task). Participants then completed a second baseline trial on the driving task. Following completion of each dual task condition, participants completed the SUS and the

questionnaire specific to that concept. To conclude the session, participants completed the general questionnaire.

3.2 Results

3.2.1 Global Usability

Mean SUS scores were moderate, ranging from approximately 52 to 66 points. Concept A scored the highest (M 65.9, SD 19.3) and Concept B received the lowest score (M 51.8, SD 17.5). By implication, Concept C was associated with a mid-range score (M 56.3, SD 19.7). A one-way repeated measures analysis of variance (ANOVA) indicated that there was a significant difference in SUS score across concepts ($F(2,58) = 5.35$, $p = 0.01$). To determine the source of the difference, a series of three paired sample t-tests with Bonferroni adjustment (to control for potential Type I errors due to multiple comparisons) was conducted. Concept A was rated as being significantly more usable than Concept B ($p < 0.017$). There were no other significant differences between concepts.

3.2.2 Effectiveness

Based on the rankings collected as part of the general questionnaire, participants scored Concept A as being the most effective of the three and Concept B as the least effective. Concept A's relatively high ranking was attributed to its simpler and more familiar list arrangement. Further scrutiny of the responses to questions provided as part of the concept-specific questionnaires highlighted two critical issues with respect to Concepts B and C. Firstly, regarding Concept C, approximately half of the participants indicated that they experienced difficulty in seeing the information presented on the display. (The corresponding figures for Concepts A and B were 27 and 23%, respectively). Participants attributed this difficulty to the size of the album covers, which were perceived as being too small to be readable and thus, of little value. Secondly, regarding Concept B, only 30% of participants expressed that the direction in which they turned the rotary control corresponded, in their mind, with the direction turning the control actually caused the list to scroll. (The corresponding numbers for Concepts A and C were 93 and 97%, respectively.) As with the Phase 1 prototype, turning the control clockwise caused the list to scroll upwards. For the majority of participants, this was counter to their expectations.

3.2.3 Efficiency

Participants' rankings for efficiency paralleled those for effectiveness. That is, Concept A was deemed to be the most efficient of the three concepts and Concept C was considered the least efficient. This pattern is consistent with the objective data on music selection performance.

Data on the mean number of task items completed per minute are summarised in Figure 3 for each of the concepts under baseline and dual task conditions. A two-way repeated measures ANOVA revealed a significant main effect of condition ($F(1,28) = 132.57$, $p < 0.001$), indicating that, overall, fewer music selection tasks were completed per minute under dual task than under baseline conditions. This pattern was consistent across the three concepts ($F(2,56) = 1.38$, $p = 0.26$). Nonetheless, there was a significant main effect of concept (F

(2, 56) = 17.08, $p < 0.001$). A series of three paired sample t-tests with Bonferroni adjustment revealed that significantly fewer music selection items were completed per minute when participants used Concept B than when using either Concept A or Concept C (all $p < 0.017$). There was no significant difference between Concepts A and C in the mean number of items completed per minute. Indeed, it is noteworthy that, even though use of Concept C involved an initial extra step (i.e. search by letter), performance on the music selection task was not adversely affected by this additional step.

Participants attributed the relatively low efficiency of Concept B to the issue concerning scrolling direction. Across concepts, participants suggested that efficiency could be improved by correlating the speed of scrolling through a list with the speed at which the rotary control is turned, such that a quick turn of the rotary control would result in a fast scroll through the current list.

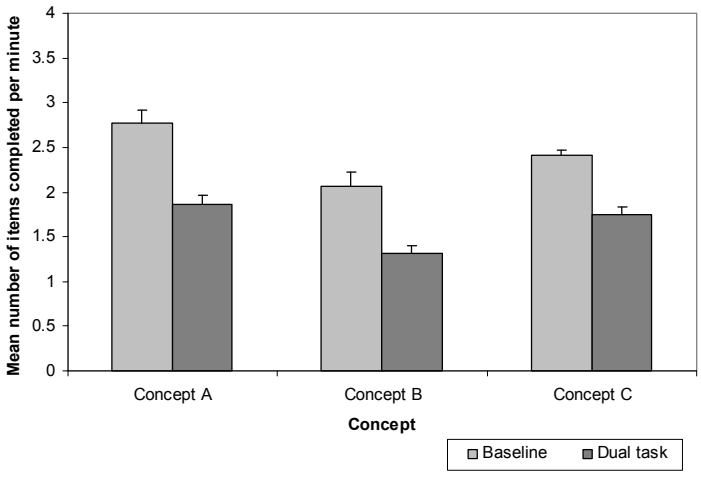

Fig.2. Mean number of music selection items completed per minute under baseline and dual task conditions for each concept (Error bars show +SEM)

3.2.4 Satisfaction

Satisfaction rankings followed a slightly different pattern to those for effectiveness and efficiency. Concept C was rated as the most satisfying to use and Concept B was considered the least satisfying to use of the three concepts. Concept C's high ranking was attributed to its aesthetic appeal, which was achieved through the use of the album art. Concept B's low ranking was attributed to participants' frustration concerning scrolling direction.

3.3 Discussion

Across concepts, global usability scores were moderate. Nonetheless, Concept A (standard) was rated as the most effective and most efficient. This was largely the result of its simpler and more familiar format. Concept C (cover art) was rated second in effectiveness and efficiency, however, it was rated the highest

in satisfaction. While participants liked the cover art concept, there were certain features about the concept (namely, the size and density of graphics) which were felt to impact adversely on the concept's effectiveness and efficiency. Concept B (fisheye modified) was rated the lowest in effectiveness, efficiency and satisfaction. The main usability issue associated with Concept B was the direction of scrolling. That is, the direction in which the list would scroll in response to a turn of the rotary control in a given direction was the reverse of expectations. This element of Concept B had an overwhelming impact on participants' perceptions of the concept, and also on participants' ability to perform the music selection task. It is interesting to note that the effect on lateral driving performance did not differ significantly between the concepts (see [8]). Nonetheless, other driving performance measures may yield a different outcome.

On the basis of the Phase 2 findings, several suggestions for design improvement were proposed and discussed with industry-based IVIS designers and engineers. Key suggestions were as follows. For Concept B, it was suggested that the direction in which turning the rotary control causes the list to scroll should be reversed. Thus, turning the rotary control in a clockwise direction should result in the list scrolling downwards. For Concept C, as album information was deemed to be too difficult to decipher because of the size and density of the graphics, it was suggested that only one album cover per letter appear on the display. Across concepts, it was suggested that consideration be given to options for improving scrolling rate. Finally, it was recommended that, following implementation of the suggestions, a further phase of usability testing be undertaken involving, if practicable, a more immersive and realistic driving environment.

4 CONCLUSION

In designing IVIS it is critical that user needs and expectations are taken into consideration. This is particularly important given the distracting potential of such technologies. A human-centred design approach, in which usability is assessed as part of an iterative process, can help to achieve such a goal. Central to the usability assessment process is the use of goals (e.g. effectiveness, efficiency, satisfaction) to guide the collection, analysis and interpretation of usability data, and the use of a suite of complementary tools for the collection of usability data. The case study described here used a cognitive walkthrough approach with experts followed by an experimental, lab-based study with potential users, to assess the usability of three IVIS information presentation concepts for music selection. In general, each method was effective in highlighting areas for design improvement and was sufficiently sensitive in differentiating the concepts on the basis of their usability.

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