

An Evaluation of Age, Gender, and Technology Experience in User Performance and Impressions of a Multimodal Human-Machine Interface

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Abstract

The impact of age, gender, and technology experience on acceptance and quality of interaction was evaluated using an informational retrieval system combining manual control elements and a visual display with a naturalistic conversational speech based interface (*City Browser*). In addition to the technical challenges of developing useful human machine interfaces (HMIs), there is increasing recognition that individual characteristics can greatly influence potential users' interaction with new technologies and thus impact adoption. However, there is not a clear consensus as to what individual factors are most significant and under what conditions. Data was analyzed from 72 participants drawn from three age groups (25-34, 45-54, and 65-74 years) and closely balanced by gender. While there was a nominal decrease in task completion with age, the difference between age groups was not statistically significant. Gender significantly impacted performance and was also reflected in more positive ratings of various features by males. Overall, younger and older adults alike reported generally positive evaluations of the HMI with interactions between age and previous technology experience in various ratings. It is suggested that one reason for the apparent lack of a major age effect can be traced to the training provided to introduce users to the HMI.

Keywords: human-machine interface, in-vehicle technologies, usability evaluation, technology learning, older drivers

1. Introduction

In some cases, individuals who might benefit the most from new technologies may be the least prepared, capable, or willing to interact with a novel or otherwise unfamiliar human-machine interface (HMI). Older individuals are often seen as having more difficulty interacting with new technologies, in particular with HMIs that are either at variance with their existing mental models for device interaction or for which they have no reference at all [1-5]. Gender and previous level of technology experience/technology anxiety have also been found to be modest predictors of quality of interaction with new technology [6-8]. Identifying and developing an understanding of factors that impact technology acceptance and adoption have important implications both for industries that wish to supply products and to potential customers that might benefit from them.

Avoidance of new HMIs is becoming increasingly difficult. One area where this is particularly evident is in automobiles. The basic user interface for the modern automobile is undergoing a rapid transformation. New features such as lane departure warnings and adaptive cruise control along with an abundance of infotainment options ranging from DVD players to navigation systems are being added on top of more basic lighting, radio, and

environmental controls. As the clutter of discrete manual controls increases, it becomes increasingly difficult to provide functionality for each system in a manner that allows for safe and effective interactions with the system. In addition, dashboards aesthetically appear uninviting and overly complex. This has led to the introduction of a range of multifunctional interfaces, such as the multi-axial rotational controllers, e.g. iDrive, COMAND and MMI, computer-style display screens that can change the HMI dynamically to support specific functions, and the development of speech interfaces to reduce the need to manually adjust controls. While these advanced HMIs offer advantages in terms of reducing the number of discrete controls, they potentially require more of the user in terms of their learning to successfully navigate and use.

This creates a dilemma in that individuals who might potentially benefit the most from advanced technologies may be the most challenged by the HMI. For example, older drivers may benefit substantially from route finding assistance, yet may be challenged in learning how to use global positioning system (GPS) based navigation systems [9]. As naturalistic voice recognition technology has advanced, it presents itself as an appropriate addition to the automotive user interface, being able to address some of the shortcomings of the aforementioned systems [1]. Regardless of the nature of an HMI, evaluation of the extent to which users of different ages, backgrounds, and experience are successful in interacting with a new system is a critical aspect of both system development and introduction of the technology to the general public [4].

1.1 City Browser HMI

City Browser is an experimental HMI developed by the Massachusetts Institute of Technology Computer Science and Artificial Intelligence Laboratory (CSAIL) to explore and refine naturalistic conversational speech interface techniques for accessing informational databases [10]. The automotive version provides traditional GPS based navigation information in addition to allowing users to search a database of 6,146 restaurants, 564 hotels, 42 museums, and 134 subway stations in the Boston metropolitan area [11]. Users can locate addresses on a map, obtain driving directions, and acquire more detailed information on establishments, such as phone numbers, hours of operation, and distance from current location. In the case of restaurants, users can also find information such as type of food and expense range. The speech recognition and natural language understanding capabilities of the system are described in detail in [12, 13]. The prototype automotive version of *City Browser* is deployed in a BMW 530xi sedan [14]. It is a multimodal HMI that uses the car's built-in display screen, sound system and iDrive controller (see [11, 14, 15] for images showing details of the implementation). Speech is captured through an array microphone positioned on the driver's sun visor.

In addition to spoken language, the *City Browser* interface can be navigated using the iDrive multi-axial rotary controller. Users can rotate the controller to scroll through lists, translate the controller left and right to move through screens, and push down to make selections. To speak with *City Browser*, users press and hold one of two dedicated speech buttons. Natural language understanding is performed in context. For example, after highlighting a restaurant in the list of results, a user could say, "Give me directions" to obtain directions to the highlighted restaurant.

City Browser also includes a context-sensitive speech suggestion generator [16], which produces on-screen suggestions to help guide users to request information. Suggestions automatically appear after the user makes two requests that are not understood by the system. They can also be accessed by navigating to the help screen with the iDrive controller. Suggestions are generated dynamically using the content of the database. This feature is designed to aid users new to the system and is not intended to be used by drivers while in motion.

1.2 Focus of Present Report

The data presented in this report were collected as part of a study having two primary goals: 1) to obtain additional speech interaction samples from males and females across a broad age range to aid in further refining the speech and context recognition features of the system, and 2) to contribute to a usability evaluation. The present report focuses on the usability evaluation, particularly exploring the extent to which demographic characteristics such as age, gender, and previous level of technology experience relate to user success and satisfaction with the system. Pilot testing suggested that older individuals appeared to have difficulty understanding how to interact with the controller to navigate and select options. Consequently, a structured introductory training protocol was developed to introduce all users to the controller and other basic features of the HMI with the goal of minimizing such effects.

2. Methods

2.1 Participants

Drivers from three age groups (25-34, 45-54, and 65-74 years) were recruited using online and newspaper advertisements. Following initial phone or e-mail screening, 94 reported to the study site. Participants were required to be active, experienced drivers, defined as driving one or more times a week and having held a valid driver's license for three or more years. Participants were required to be relatively healthy based on self-report. Upon review, two individuals were dropped from the analysis for not meeting eligibility requirements. One participant was dropped because of a protocol error. As this was a prototype system, there were 19 cases where technical errors occurred and required a system restart via manual intervention by a research associate. Cases where technical errors occurred were dropped so that the evaluation focused on the HMI design and not the prototype nature of the implementation. Cases where the speech detection algorithm and program logic had difficulty interpreting user requests were included as that was considered part of the fundamental system evaluation. The final sample consisted of 72 participants.

2.2 Procedure

All participants were first given an overview of the project's objectives and the experimental protocol. They were then required to read and sign an informed consent approved by the local institutional review board. Participants were asked to complete a questionnaire that assessed driving habits, technology exposure, and demographics. Once the questionnaire had been completed, the participant entered the instrumented vehicle. The vehicle was located in a parking lot and the evaluation was carried out under parked, non-driving conditions. Approximately three minutes of prerecorded instructions were provided to introduce the interface including the iDrive multi-axial rotational controller and the mode of speech interaction. When errors in operation of the iDrive controller or speech interaction occurred during the training period, a research associate seated in the rear of the vehicle clarified the task in a manner similar to an interactive tutorial. A key aspect of this technology introduction was the demonstration of the interface so that participants were directly guided through the interaction logic to aid in development of their mental model of the system design [4]. A portion of the recorded introductory tutorial is reproduced below:

"In the screen in front of you, City Browser shows a map with your current location. A small blue triangle indicates the position of the car and which way it's facing. You can control what you see on the screen by using the iDrive controller, which is a silver knob located to your right near the gear shifter. You can use your hand to spin the controller, and to shift it left, right, forward and back. You can also push down on it like a button. Now, find the controller and put your hand on it. *[PAUSE - research assistant verifies]* First, try pushing it to the right, away from yourself. This should bring you to a help screen, which shows suggestions of things you might want to say to City Browser. *[PAUSE - research assistant verifies]* Now, try spinning the controller clockwise. You should be able to scroll down the list this way. To scroll back up, spin the controller counter-clockwise."

... "Now we're going to try speaking to City Browser... When you're ready, give it a try. Hold down the button, say 'Show me Chinese restaurants', and then release the button. *[PAUSE - research assistant verifies]* You should now see several Chinese restaurants which are near where you are right now. You can scroll through the list by spinning the controller. To hear more information about one of them, you can select it by pressing down on the controller."

Ten experimental tasks were then presented. The tasks were designed to encompass typical navigation and information goals. Subjects were asked to find points of interest (POIs) such as restaurants, hotels, and museums, to get driving directions to particular addresses or POIs, and to obtain information such as phone numbers. For example: "You're meeting up with some friends in Cambridge and want to take them to a Chinese restaurant. Find one and get directions to it." (See [12] or [15] for full listing of tasks.) The tasks were designed to be of easy, medium, or hard difficulty. The first three tasks were intended to be easy to familiarize the subject with the interface and allow him or her to gain confidence. The subsequent seven tasks comprised a mixture of presumed medium and hard tasks. In instances where a participant made no progress towards the completion of the task (e.g., task completion time surpassed three minutes with no progress), the experiment was advanced to the next task.

The tasks were presented in the same sequence for all participants. To minimize biasing participant's pronunciation when they interacted with the speech interface, the tasks were printed on index cards and handed to participants rather than using auditory presentation. There was a 25-second pause between tasks while the system reset. Following the interactive portion of the experiment, a second questionnaire was presented to evaluate each

participant's impression of the system, likes and dislikes, and measures of effort and frustration. Participants were compensated \$40 for their participation.

Participants' interaction with the system was recorded using a microphone and videos of the face, hand, and in-car display. These records were referred to as needed to check instances where the session log indicated that technical issues precluded use of the case for the current analysis.

2.3 Measures & Data Analysis

Task completion counts were recorded by a research associate. Statistical analyses were carried out using between subjects ANOVAs (SPSS version 16) unless otherwise noted. An alpha level of .05 was selected for establishing significance.

3. Results

3.1 Sample Characteristics

As can be observed in Table 1, males made-up 53% of the sample and were evenly distributed across the three age groups. Females were somewhat underrepresented in the 25-34 year old group (making up 41%) while being closely balanced in the two older groups.

Table 1: Distribution of participants by age and gender [with mean age in years]

	25-34		45-54		65-74		Combined	
Female	9	[30.3]	12	[49.6]	13	[68.4]	34	[51.7]
Male	13	[27.2]	13	[47.7]	12	[67.3]	38	[46.9]
Combined	22	[28.5]	25	[48.6]	25	[67.8]	72	[49.1]

3.2 Task Completion

As shown in Table 2, most participants were quite successful at completing the tasks with an overall mean completion of 9.26 out of the 10 tasks. Considering completion rates in more detail, 68 out of the 72 participants completed eight, nine or ten tasks, 55.6% completed ten tasks, 23.6% completed nine tasks, and 15.3% completed eight tasks. Four participants, all women, were statistical outliers: a 30-year old who completed seven tasks, a 32-year old who completed seven tasks, a 66-year old who completed six tasks, and a 67-year old who completed six tasks. There was a significant effect of gender on task completion ($F(1,70)= 12.463, p=.001$) with males completing a mean of 9.63 tasks versus 8.85 tasks for females. There was a trend in the means suggesting a slight drop in completion rates by age, but the differences by age group were not statistically significant ($F(2,69)= 0.908, p=.408$).

Table 2: Mean and (SD) of number of tasks completed [out of 10] by age and gender

	25-34		45-54		65-74		Average	
Female	9.00	(1.23)	8.92	(0.79)	8.69	(1.44)	8.85	(1.16)
Male	9.85	(0.56)	9.46	(0.78)	9.58	(0.67)	9.63	(0.68)
Average	9.50	(0.96)	9.20	(0.82)	9.12	(1.20)	9.26	(1.01)

Participants self-rated their level of technology experience on a 10 point scale (1=very inexperienced, 10=very experienced) prior to being introduced to the task. A modest positive relationship between this estimate of technology experience and task completion appears in a Pearson correlation coefficient of .285 ($p=.01$). However, this relationship may be largely gender mediated as the correlation coefficient between gender and task completion was .437 ($p<.001$). Running a linear regression considering age, gender, self-rated technology experience, and GPS ownership on task completion rates shows a significant effect of gender ($p=.001$), but not technology experience ($p=.158$), age ($p=.446$), nor GPS ownership ($p=.774$). Thus, adding age, self-rated technology experience or GPS ownership did not add significantly to the regression relationship beyond that provided by gender. Age and technology experience showed a significant inverse relationship as reflected in a correlation coefficient of $-.326$ ($p=.004$), but again, age was not significantly related to number of tasks completed ($p=.446$).

Ownership of a GPS system was explored as an estimate of technology experience that might affect initial success with the system. However, this did not have a significant effect on task completion ($F(1,70)= 0.346, p=.558$). Mean

completion rate for participants who owned a GPS system (N=25) was only nominally greater at 9.36 versus 9.21 (N=47) for those who did not.

3.3 Subjective Experience

Although some participants were more successful at completing the tasks than others, results from the post-experimental questionnaire indicated an overall positive inclination towards the system. Participants rated interaction with the system on 7-point scales with strongly agree and strongly disagree as end points. Considering a ranking of four as a neutral evaluation, the majority of participants ranked the system as accurate (78%) and useful (81%). In addition, 76% reported enjoying using the system, 86% thought the system was easy to learn, and 75% said they would actually use the system if it was available.

When asked to rank how difficult the tasks “were on average compared to things you usually do while driving” (1=not at all difficult to 10=very difficult), the ranking was toward the less difficult end with a mean rating of 4.19. As detailed in Table 3, females ranked the tasks as slightly more difficult than males, but the difference was not significant. The mean ranking for ease of getting information from the system was also on the positive side at 4.53 on the same scale. The greater success of males in completing the tasks is reflected in that men found it easier to get information from the system, felt the system understood them better, and enjoyed using the system more. Overall ranking of the extent to which participants enjoyed using the system was quite high with the mean value being 2.58 (1=strongly agree, 7=strongly disagree). There were no significant differences by gender on the extent to which participants liked or disliked the computer display or using the rotational controller (both being ranked slightly above neutral toward the liked direction). Both genders were similar in their general dislike of the sound of the voice used in the prototype interface.

Table 3: Significance of Gender in rating various aspects of the system

Item Content & Gender Significance	Males	Females	ANOVA
No significant difference in ranking of difficulty of tasks compared to other driving tasks (<i>scaled 1-10 where 10 is more difficult</i>)	4.03	4.37	F(1,68)= 0.3, p=.578
Males found it easier to get the information they requested (<i>reversed scaling 1-10 where lower is easier</i>)	3.84	5.29	F(1,70)= 8.2, p=.005*
Males felt the system understood what they were saying better (<i>scaled 1-10 where 10 is better</i>)	6.87	5.71	F(1,70)= 4.5, p=.038*
Males enjoyed using the system more, although rating was high for both genders (<i>scaled 1-7 where 1= strongly agree that they enjoyed using the system</i>)	2.24	2.97	F(1,70)= 4.5, p=.037*

While age was not a statistically significant factor in the total number of tasks completed, the 65-74 year old group did not rate the system quite as highly on the subjective scales on how easy it was to get the information they requested. For other scales, such as the extent to which participants enjoyed using the system, there were no significant age differences. Details are provided in Table 4.

Table 4: Significance of Age in rating various aspects of the system

Item Content & Age Significance	25-34	45-54	65-74	ANOVA
No significant age effect for difficulty of tasks compared to other driving tasks (<i>scaled 1-10 where 10 is more difficult</i>)	3.68	4.00	4.83	F(2,67)= 1.2, p=.295
Age impacted rating of how easy it was to get the information they requested (<i>reversed scaling 1-10 where lower is easier</i>)	4.27	3.88	5.40	F(2,69)= 3.2, p=.045*
No significant age effect on how participants felt the system understood what they were saying (<i>scaled 1-10 where 10 is better</i>)	6.91	5.84	6.28	F(2,69)= 1.2, p=.313
No significant age effect on the extent to which participants enjoyed using the system (<i>scaled 1-7 where 1= strongly agree that they enjoyed using the system</i>)	2.45	2.28	3.00	F(2,69)= 1.6, p=.212

As shown in Table 5, participants who owned a GPS system ranked the system somewhat higher on usefulness thus presenting a trend in which GPS owners felt that the system understood their requests on a greater level. However, while owning a GPS appeared to influence these expectations about system function, GPS ownership was unrelated to participants' effectiveness in interacting with the system (as measured by task completion) or in the extent to which they rated enjoying interacting with the system.

Table 5: Significance of GPS Ownership in rating various aspects of the system

Item Content & Significance of GPS ownership	Yes	No	ANOVA
No significant difference in ranking of difficulty of tasks compared to other driving tasks (<i>scaled 1-10 where 10 is more difficult</i>)	4.08	4.24	F(1,68)= 0.1, p=.801
No significant difference in ease of getting the information requested (<i>reversed scaling 1-10 where lower is easier</i>)	4.16	4.72	F(1,70)= 1.0, p=.315
Trend for GPS owners feeling that the system understood what they were saying better (<i>scaled 1-10 where 10 is better</i>)	6.92	6.0	F(1,70)= 2.5, p=.121
GPS owners ranked the system as more useful (<i>scaled 1-7 where 1= strongly agree that the system was useful</i>)	1.76	2.57	F(1,70)= 5.1, p=.027*
No significant difference on ranking of the extent to which participants enjoyed using the system (<i>scaled 1-7 where 1= strongly agree that they enjoyed using the system</i>)	2.40	2.68	F(1,70)= 0.6, p=.453

4. Discussion

The current study extends on an earlier pilot investigation [11] of an automotive version of the *City Browser* multimodal HMI by employing a larger sample and a broader age range. Data from 72 participants drawn from three age groups (25-34, 45-54, and 65-74 years) and relatively balanced by gender was analyzed to assess the extent to which the demographic factors of age, gender, and technology experience were related to objective and subjective aspects of the usability of the system. It had been anticipated that the flexibility of the natural speech aspect of the user interface might alleviate challenges that some individuals have in learning to use less flexible, fixed command based speech interfaces. Similarly, a guided introduction to the HMI was provided to assist participants in developing a mental model of the operation of the system.

Gender was found to have a modest, but statistically significant impact on the number of information retrieval tasks that were successfully completed. While the overall task completion rate for the sample was quite high, males were slightly more successful in the total number of tasks completed. Males also gave the system higher ratings on ease of getting information, feeling that the system understood what they were saying, and the extent to which they enjoyed using the system. Nonetheless, overall ranking of most features of the system were on the positive side for both genders and there were no significant differences by gender in the ranking of other individual features such as the display screen, rotational controller, or voice interaction.

There was a modest relationship between self-rated technology experience and task completion rate. However, part of this relationship may have been associated with gender since males also tended to rate themselves higher in

technology experience. Further, when age, gender, self-rated technology experience, and GPS ownership were considered in a regression analysis, gender alone provided the majority of the predictive power for task completion while the addition of age and technology experience did not significantly increase the predictive power of the model. GPS ownership was explored as an independent measure of technology experience, but it was found to be unrelated to task completion rate. GPS owners rated the system as slightly more useful and there was a trend for them to give the system a higher rating in how well it understood them. This may reflect a somewhat more positive bias toward navigation systems in general by this group.

Although the group means for the task completion rate decreased slightly with age and participants' rating of the difficulty of the tasks compared to other driving tasks increased with age, neither trend was statistically significant. There was a statistically significant effect of age on ratings of how easy it was to get the information that was requested where the 65-74 year old group gave the system the least positive ranking, suggesting that the oldest group had to work harder or found it more challenging to obtain the same level of success as younger individuals. However, this effect was still modest in terms of absolute differences. Thus, the stereotype that new technology is inherently more difficult for older participants to learn and use [1] is brought into question.

In general, users rated the tasks associated with using *City Browser* as being slightly less difficult "on average compared to things you usually do while driving". Since the *City Browser* tasks were carried out while the vehicle was stationary, no assessment was made of workload or cognitive absorption associated with carrying out the inquiry tasks while the vehicle was in motion. There is currently significant concern around the issue of driver distraction and a lack of consensus around what kind and form of secondary tasks are appropriate while driving [17, 18] and for what populations [19]. Several features of *City Browser*, such as the natural speech interaction and the multi-axial rotational controller for centralization of manual control interactions, were designed to simplify the HMI interaction. Nonetheless, potentially absorbing interactions such as exploring points of interest and reviewing details of restaurant selections are most likely tasks best done while the vehicle is parked. In recognition of such concerns, many navigation systems carry injunctions that state that entry of navigation locations should only be done while the vehicle is stationary. Care should be exercised when advanced information systems are developed and implemented in vehicles so that safety is not compromised and basic research further developing our understanding of these issues is indicated.

4.1 Conclusion

To the extent that age and/or technology experience impact the ease with which individuals are able to successfully master new technologies, the findings presented here suggest that the overall design of the automotive version of *City Browser* natural speech HMI combined with the technology introduction training appear to have minimized the impact of these demographic considerations.

4.2 Limitations

While participants represented a reasonable sampling across the age range of individuals likely to purchase automobiles and was fairly well balanced by gender, it is likely that the sample was somewhat underrepresented in individuals who are technology avoidant since recruitment for the study indicated that it was intended to evaluate the usability of a newly developed voice recognition navigation system. A more complete assessment of the significance of technology experience would require a fully random sampling of technology backgrounds. The assertion that the natural speech interface and the introductory technology training minimized the reported impact of age and technology experience factors on the usability of the system is purely suggestive. An experimental design comparing a fixed command based speech interface versus the natural speech interface would be required to test the first assertion and a comparison of individuals who received the introductory training versus those who received limited assistance would be required to assess the second.

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