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Driver safety and information from afar: An experimental driving simulator study of wireless vs. in-car information services

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Abstract

Cars have changed from pure transportation devices to fully interactive, voice-based systems. While voice interaction in the car has previously required on-board processing, the growing speed and ubiquity of wireless technologies now enable interaction with a distant source. Will the perceived source of the information influence driver safety, responses to the information, and attitudes toward the computer system and car? A between-participants experimental design ($N = 40$) of computer proximity—in-car vs. wireless—using an advanced car simulator, found that people's driving behavior, verbal responsiveness, and attitudes are affected by computer proximity. A path analysis shows two counterbalancing effects of computer proximity on driving behavior: drivers feel more engaged with the in-car system than the wireless system, which leads to safer driving behavior; however, drivers also drive faster while using the in-car system than the wireless system, which leads to more dangerous driving behavior. Consistent with greater feelings of engagement with the in-car system, people also feel less discontentment with the in-car system and self-disclose more to the in-car system. Positive perceptions of information content also lead drivers to be more persuaded by driving recommendations. Implications for the design of wireless systems are explored.

1. Introduction

Computers in cars are moving from just control under the hood to actively interacting with the driver (Boehm-Davis et al., 2003; Marcus, 2004). They are providing services such as rich computer navigation assistance, providing moment-by-moment relevant information to drivers about upcoming traffic, road conditions, local weather reports, and driving directions. Such computer-based services could also provide other potentially desirable information such as travel destinations, proximate gas stations, entertainment, commerce, education, health monitoring, car maintenance instructions, etc. (Lee et al., 1999; Marcus, 2004).

With existing high demands on a driver's visual attention, many on-board computer systems utilize speech technologies. While speech-based interfaces may seem to be a safer option than graphical user interfaces in cars, there remains a concern that the cognitive demands associated with richer communication will impair driving safety. As human-computer interaction becomes more enriched and engaging, there may be problems analogous to those involving drivers talking on mobile phones on the road (McKnight and McKnight, 1993; Redelmeier and Tibshirani, 1997; Strayer et al., 2003, 2005), particularly because speech-based interfaces involve two-way communication between driver and computer, unlike the existing one-way communication between the radio (and other outputs) and the driver.

Thus, as people interact with information services in cars, human perception, safety, and system use must be investigated and considered in the early stages of interface design. The practical question is how one should design such vehicle user interfaces that are helpful to drivers and, more importantly, do not hinder safe driving performance. Simultaneously, the theoretical question is what model predicts the kinds of responses observed from drivers interacting with computers while on the road.

A combination of real world mishaps and controlled experimental studies has shown that several factors significantly affect driver responses to voice interfaces in cars, including perceived voice gender, emotion, and even

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age. The BMW 5-series released in Germany included a voice-based navigational system, featuring a computer-generated voice with female characteristics. Although these drivers were well-aware that the voice was computer-generated, they reacted with gender stereotyped responses, ultimately rejecting the female voice and demanding a product recall (Nass and Brave, 2005). BMW switched the female voice to a male voice and re-cast the navigational system voice in the role of a co-pilot (Macneil and Cran, 2004). Along with gender, experimental studies have shown how perceived voice emotion affects not only driver attitudinal responses to the interfaces, but even safe driving behavior: drivers whose emotions are matched by the emotions of the voice interface feel more positively about the system and drive more safely (Nass et al., 2005). Perceived age also affects driver responses to in-car vehicle user interfaces. Contrary to intuitions that older drivers would prefer older voices and younger drivers would prefer younger voices, older drivers actually prefer younger voices as their Driver's Assistants rather than older voices because they attribute characteristics of younger people to those Driver's Assistants, e.g., better eyesight (Jonsson et al., 2005). While significant differences are readily predicted by evocative interface characteristics of gender, emotion, and age, there are more subtle characteristics of computer interfaces that are yet to be explored.

One of the most important and unappreciated trends in car systems is that information no longer comes solely from the car. In the traditional model of interactive car systems, the navigation system sat in the car and the driver manually controlled features such as windows, lighting, climate, music, etc. It is a historical happenstance that the computer which controls all of these services is placed in the car. Today, there is no reason why the car could not be wirelessly controlled by a computer elsewhere, e.g., remote-controlled heating for the car so that one can warm it up before going out onto the snowy roads. Taking this type of remote service further, new wireless technologies such as GPS, GPIS, and OnStar, allow for a whole new set of services to appear, including location-based services, remote emergency services, and satellite radio. For example, the OnStar system provides remote emergency services by trained emergency agents via hands-free calling for drivers with built-in microphones, connection to a cellular network, and GPS technologies.

As vehicle user interfaces are being deployed as both on-board computers and as receivers and senders of external information, communicating wirelessly from afar, there may be more at stake in these different implementations than mere engineering trade-offs. While these content-based differences could be readily studied in an experimental setting, there are more interesting questions to ask from a theoretical perspective. For example, how and why would the proximity of computer sources make a difference in user perceptions, attitudes, and behaviors? Based on existing research in computers as social actors (CASA) theory (see Section 2.1) and findings in interpersonal interaction between humans, this research focuses on the idea that computer proximity will affect people in the same way that human proximity affects them in interpersonal contexts.

This experiment was also part of a broader inquiry into how people make sense of the technological decoupling of bodies and brains from faces and voices of social actors (Nass and Brave, 2005). Though this decoupling is not typical in interpersonal interaction, it is quite common in technologically mediated interactions such as those introduced by the telegraph and telephone (Kahn and Whitehead, 1994). Similarly, older technologies such as written language have introduced a decoupling of language use from co-located and synchronous interaction with conversational partners. More recently, technologies such as live radio and the Internet also separate bodies and brains (e.g., web servers) from faces and voices (e.g., interfaces presented on each user's personal computer). The broader theoretical research question at hand is: how does the perception of communicative sources as physically distant affect interactions between communicators? In this particular context, how does the perception of computer proximity affect interactions involving drivers and vehicle computer interfaces?

2. Computers as sources of information

2.1. Computers as social actors

Though computers have been thought to be merely a medium through which communications are transmitted, the CASA theory (Reeves and Nass, 1996; Nass and Moon, 2000) proposes that people actually engage in the same kinds of social responses that they use with humans. This theory is also supported by numerous experiments on computer voice interfaces (Nass and Brave, 2005). These social responses to people and to computers are automatic and largely unconscious (Reeves and Nass, 1996; Nass and Gong, 2000).

While approaches to human–machine interaction have made moves to address machines as social actors (e.g., Hoc, 2000), this approach is a new way of looking at *computer*s as sources of information rather than as a medium for communicating information. This experimental paradigm prescribes taking an existing social psychological finding in human–human interaction, replacing at least one of the humans with a computer, and replicating the original human–human experimental findings, thereby suggesting new computer interface design guidelines as well as opening new questions for the realm of human–computer interaction. This study is one instance of an experiment in the CASA paradigm, investigating social responses to differences in computer proximity, basing predictions upon known social psychological responses to human proximity.

2.2. Proximity of sources

Physical proximity is a salient feature in human–human interaction, particularly because physical proximity is often paired with a greater potential physical and social risk (Dreyfus, 2001), a higher frequency of interaction, etc. From the literature on interpersonal attraction, we know that physical proximity is among the important factors for forming friendships between people (Festinger et al., 1950). From the literature on computer-mediated communication, we know that distant collaborators are more likely to be persuaded by a collaborator believed to be in the same city as opposed to in a more distant city (Bradner and Mark, 2002). In a review of collocated and non-collocated collaborative groups, Olson and Olson (2000) also conclude that distance between people still matters even in this age of "virtual collocation."

Similar to such human–human interaction studies, Moon (1998) demonstrated that human–computer interaction works in much the same way. Telling participants that the computer they were interacting with was the computer that was right in front of them (non-networked), in a nearby city, or in a city several thousand miles away, caused significant differences in interactions with computers; these results were consistent with individual's responses to humans at various degrees of physical proximity. Participants were more likely to engage in more impression management and less self-disclosure to computer interviewing systems that were supposedly physically closer as opposed to further away from the participant's location.

In line with the CASA paradigm, this study hypothesizes that drivers will respond to in-car vs. distance computers in much the same way that they respond to in-car passengers vs. remote conversationalists. There are several dependent variables that may be affected by more proximate (in-car) vs. less proximate (wireless) computer systems. Specifically, based on Festinger et al.'s (1950) findings, drivers will feel more positively and friendly toward the more proximate computer than the distant one. This may become manifest in self-reports of more comfort and engagement with the proximate Driver's Assistant than the distant one. It may also appear as more disclosure of personal information about oneself to the more proximate Driver's Assistant than the distant one (Moon, 1998). Based on Bradner and Mark's (2002) findings, drivers will be more persuaded by a proximate computer than a distant one.

3. Driving context

3.1. Implementation of in-car services

These issues of computer source proximity are particularly relevant to the driving context in which providing information services to drivers is usually done in one of two ways: computers are either put on-board the car or are centrally stationed in a building and wirelessly communicate with individual cars from a distance, e.g., OnStar. Given the known influences of human proximity and the replication of several of those influences from computer proximity, it is likely that presenting information to the user as coming from a computer in the car (i.e., nearby) vs. wirelessly (i.e., far away) could have significant consequences.

3.2. Driver distraction

Everyday driving includes frequent distractions such as talking with passengers, grooming, manipulating stereo or climate controls, etc. (Stutts et al., 2003). While government bodies are coping with issues of public safety due to driver distractions (Pound, 2002; Transport, 2003), there is limited empirical evidence of exactly what aspects of driver interactions in cars actually hinder safe driving practices and how.

The scientific literature on driver distraction is growing as new mobile and in-car technologies are becoming available. One major driver safety concern with introducing in-car information services is whether the safety problems associated with cell phone use in cars (Redelmeier and Tibshirani, 1997) will also hold for voice-based information services in cars. Though some regions legislate against cell phone use other than hands-free sets (e.g., New York), it is not clear that hands-free cell phones improve the problem of driver distraction at all (Redelmeier and Tibshirani, 1997). Testing the hypothesis that shared awareness of road conditions helps drivers to drive more safely while talking with conversational partners, an experiment on signaling cell phone conversational partners during critical driving periods was shown to mitigate risk for drivers talking on cell phones (Manalavan et al., 2002). Similarly, providing remote callers with remote contextual displays helps to improve driving performance of drivers (Shneider and Kiesler, 2005). A shared theoretical basis of these studies with the current experiment is that it is more difficult to talk with people who do not share your local context because you share less common ground (Clark and Brennan, 1991). Kiesler and colleagues (Manalavan et al., 2002; Shneider and Kiesler, 2005) studied technologically mediated human–human interaction and manipulated the presence or absence of shared context. In contrast, the current research involved human–computer interaction and held context (and even conversational content) constant while it manipulated the driver's perception of the proximity of the computer conversational partner.

The similar research hypothesis in this study was that it would take more effort to think about talking with the remote conversational partner than talking with a proximate one because of a lack of shared context (e.g., sitting in the same car) and common ground (Clark and Brennan, 1991), thereby making it more difficult to drive while conversing with distant sources than proximate ones. This notion appears to hold true for human–human interaction (e.g., Manalavan et al., 2002); this study investigates whether it also holds true for human–computer interaction. This suggests that people would drive less safely while talking with a distant communicative partner than a proximate one because they would be more distracted by trying to maintain the conversation at a distance. However, we have anecdotally observed people slowing down their walking pace when heavily concentrating upon a conversation and speeding up when concentrating less on the conversation; therefore, one might predict that having a difficult time conversing with a distant source (as opposed to a proximate one) might lead to slowed and more cautious driving behavior. This study aimed to find out the direction of the effect of computer proximity on safe driving behavior.

While this study is similar to Moon's (1998) experiment of computer source proximity in the interviewing context, this paper is the first test of the effects of source proximity in the driving context and the first to investigate effects of source proximity upon physical performance in a safety-critical situation.

4. Method

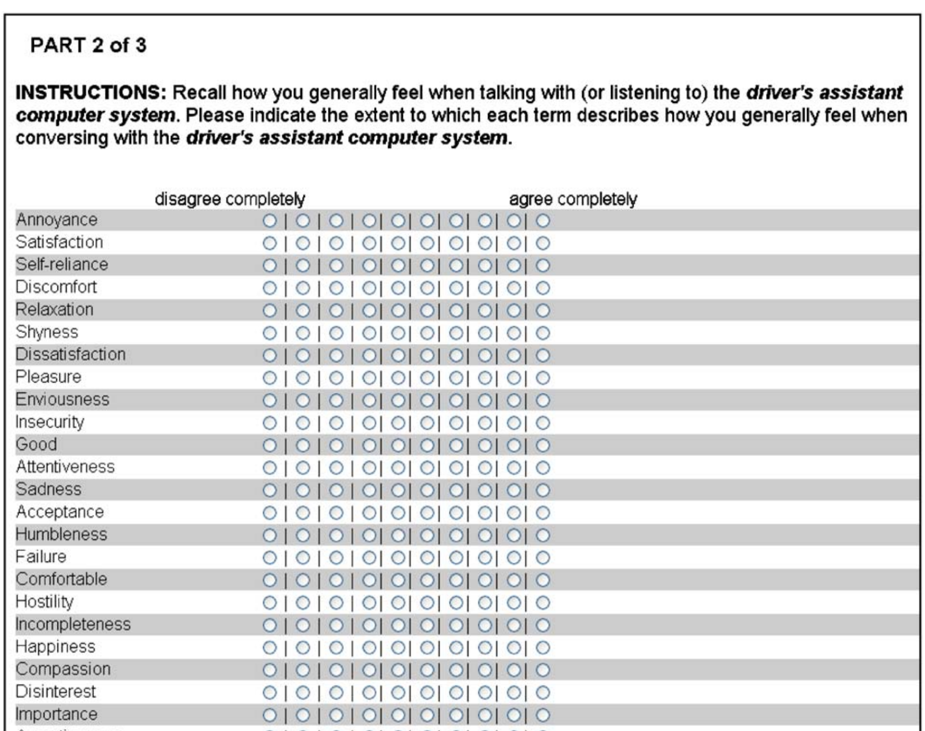
4.1. Driving simulator

Equipment used in this study include the STISIM driving simulator, a six-foot rear projection screen, a gas pedal and brake, a force-feedback steering wheel, and a real driver's seat. Though using a real car on real streets would have increased the experiment's external validity, the combination of high physical risk to participants and high variation in road conditions made it unfeasible as a safe and well-controlled way to run this study. The driving simulator was set up in a quiet room with all windows blocked. It provided a very controlled driving environment in which we pre-programmed everything from the structure of the roads to the driving conditions to the behaviors of others' cars on the road. Because we could pre-program these conditions and events into the course, we were able to control the environment to be the same across all participants.

4.2. Procedure

Twenty men and twenty women from the San Francisco Bay Area participated in this study; their ages ranged from 19 to 55 ($M = 29.0$, $SD = 9.54$); their driving experiences ranged from 2 to 37 years ($M = 12.0$, $SD = 9.59$). Participants came to the driving simulator lab, where they signed an approved human subjects consent form, were trained to use the simulator, and tried driving it both alone and with an experimenter in the room. Once participants felt comfortable with the simulator, they were given instructions to drive the simulator until the end of the course while using the speech-based computer interface called the "Driver's Assistant." Upon completing the course, the participants filled out an online questionnaire on a separate computer (see Fig. 1).

While driving, participants interacted with the Driver's Assistant. Voice prompts played at specified locations along the course. The voice prompts were scripted recordings of human voices. The scripts included persuasive



PART 2 of 3

INSTRUCTIONS: Recall how you generally feel when talking with (or listening to) the ***driver's assistant computer system***. Please indicate the extent to which each term describes how you generally feel when conversing with the ***driver's assistant computer system***.

disagree completely — agree completely

Annoyance
Satisfaction
Self-reliance
Discomfort
Relaxation
Shyness
Dissatisfaction
Pleasure
Enviousness
Insecurity
Good
Attentiveness
Sadness
Acceptance
Humbleness
Failure
Comfortable
Hostility
Incompleteness
Happiness
Compassion
Disinterest
Importance
Assertiveness

Fig. 1. Screenshot of section of online questionnaire presented to participants.

prompts such as, "There is fog up ahead. You may want to slow down since there will be poor visibility," and, "There is construction up ahead and the left lane will be closed. You could merge to the right lane now to avoid this barrier." Other prompts invited the driver to respond to requests for disclosure of personal information, e.g., "What do you look for when deciding on where to fill up gas?" A complete list of voice prompts is included in Appendix A.

The design of the experiment ensured balance for participant gender, computer voice gender, driving course, and voice prompt set (Table 1). The primary factor in the study was whether the Driver's Assistant was described as an "in-car system" or a "wireless system" (see details in Section 4.3). In each condition, half of the participants heard a male voice and half heard a female voice. In each of these conditions, approximately half of the participants were male and half were female.

Each simulated driving course was programmed to be 50 000 feet long and included rural, suburban, and urban contexts with various driving conditions including fog, open roads, careless pedestrians, and various levels of traffic congestion. Though there were computer-generated cars on the roads that behaved as drivers, the experimental participants did not actually interact with other human drivers in the simulator. Drivers all experienced essentially the same course. Though the driver was given the impression of free will in choosing a personal route through the course, even when the driver turned right or left at an intersection, the same course was then generated on the "new" road exactly as it would have been on the "old" road not taken.

To mitigate issues of a particular simulated course having confounding effects on participants, we created two similar, but not identical, driving courses: half of the participants in each condition drove course one while the other half of the participants drove course two. Both driving courses included pre-programmed roads, intersections, buildings, cars, pedestrians, etc., including a mixture of road types with rural areas with long, straight, two-lane roads, suburban areas with hot dog stands, and cities with four-lane roads and several traffic light intersections. Both driving courses also included challenging driving regions of dense fog, a sharp turn, a windy strip of road, a slippery curve, a street with many pedestrians, a two-way stop intersection with lots of cars in the cross-traffic, and a construction zone that blocked off one of two lanes of traffic.

Table 1
Experimental conditions balanced for course number, voice gender, computer proximity, and voice prompt set

Condition	Course number	Voice gender	Proximity	Voice prompts[a]
A	Course 1	Female	Wireless	Set 1
B	Course 1	Male	Wireless	Set 2
C	Course 1	Female	In-car	Set 2
D	Course 1	Male	In-car	Set 1
E	Course 2	Female	Wireless	Set 2
F	Course 2	Male	Wireless	Set 1
G	Course 2	Female	In-car	Set 1
H	Course 2	Male	In-car	Set 2

Set 1 = persuasive prompts 9–16 and disclosure eliciting prompts 11–20.
Set 2 = persuasive prompts 1–8 and disclosure eliciting prompts 1–10.
[a]Voice prompts sets.

4.3. Experimental manipulation of computer distance

The independent variable of computer distance was manipulated with variants in instructions and voice prompt content. In the in-car (proximate) condition, the experimenter told participants, "This is a prototype of a new in-car speech-based Drivers' Assistant program. The computer that provides the information is installed in your car." In the wireless (distant) condition, the experimenter told participants, "This is a prototype of a new wireless speech-based Drivers' Assistant program. It is wirelessly communicating with your car from Chicago." Analogous to radio stations intermittently announcing the station name throughout broadcasts, the voice prompt content was manipulated to intermittently remind participants of what type of system they were using (see Appendix A). For example, participants heard the Driver's Assistant say, "This information was brought to you by the In-car Driver's Assistant System," vs. "This information was brought to you by the Wireless Driver's Assistant System." Sound quality, speaker placement, and other physical indicators of computer distance were not manipulated to control for potential confounds.

4.4. Measures

4.1.1. Safe driving

Driving behaviors were measured using automated data collection by the driving simulator, including items such as time on course, speeding incidences, number of pedestrians hit, number of centerline crossings, etc.

A principle component factor analysis revealed that four of the behavioral items were most highly correlated and descriptive of unsafe driving. Because the distributions of the variables were highly diverse, the *unsafe driving score* was an index consisting of median splits on four measures: speeding incidents, traffic light tickets, center line crossings, and road edge excursions. The index was highly reliable (Cronbach's $\alpha = 0.69$). The index was calculated by summing the unweighted values of all four median split variables (coded as zero for values below the median and one for values above the median for each variable); therefore, the unsafe driving score index ranged from zero to four. The s*afe driving score* was calculated as four minus unsafe driving.

4.4.2. Fast driving

Fast driving was measured by how fast the participant completed a standard length, 50 000 foot-long, driving course. Because the course length was held constant, faster driving was indicated by shorter time driving on the course, measured as seconds spent driving with the driving simulator.

4.4.3. Attitudes: information quality, discontentment, and engagement

Attitudes were measured using web-based questionnaires presented on a separate computer. All items were measured on 10-point Likert scales.

Information quality was an unweighted, summed index of four items asking how trustworthy, helpful, relevant, and insightful the information was for the driver. They were the same items used by Moon (1998). Answers were reported on a bipolar semantic differential scale, e.g., not helpful at all (= 1) to extremely helpful (= 10). The range of possible scores for the initial index was 4 (= 1 for trustworthy + 1 for helpful + 1 for relevant + 1 for insightful) to 40 (= 10 for each of the same components). We divided by 4 to place the index on the same scale as the initial items. The index was very reliable ($\alpha = 0.86$).

Discontentment with interacting with the Driver's Assistant was measured as an unweighted, summed index based on items asking to what extent the terms "comfortable" (negatively coded), "discomfort," and "dissatisfied" described how the driver felt while interacting with the system (1 = describes very poorly to 10 = describes very well). The range of possible scores for this index, once averaged, was 1–10, as in the original items. This index components were selected via principle component factor analysis; it was very reliable ($\alpha = 0.77$).

Engagement with the system was an unweighted, summed index of how attentive and how assertive participants felt while interacting with the system. The range of possible scores for this index, once averaged, was 1–10. Both discontentment and engagement were assessed using items from a questionnaire originally used to measure perceived understanding in interpersonal contexts (Cahn and Shulman, 1984).

4.4.4. Disclosure

Participants' verbal responses to the Driver's Assistant voice prompts were recorded and transcribed. Of particular interest were the verbal responses to disclosure-eliciting voice prompts because adaptive and personalized user interfaces for vehicle user interfaces (e.g., Console et al., 2002) will require users to disclose information about themselves (whether explicitly or implicitly) to know how to adapt. For example, knowing what kinds of restaurants the driver likes to frequent provides interface agents with a model of what kinds of restaurants to recommend to the driver in the future. Following previous research (Nass and Brave, 2005; Wang and Nass, 2005), *disclosure* was measured by number of words spoken.

4.4.5. Persuasion

Persuasion was measured by counting the number of times that a driver altered driving behaviors according to the Driver's Assistant's suggestions. For each participant, there were 10 instances in which the Driver's Assistant provided a suggestion. For example, if the system suggested, "To avoid the crowd, you may want to turn right here," and the driver actually turned right when the driver typically went straight through intersections, this behavior change was counted as the driver being persuaded by the Driver's Assistant. Ambiguous behavior was not included in the persuasion count.

5. Results

The results demonstrate that there were two counter-balancing ways in which computer proximity affected safe driving behavior; proximate computers influenced participants to drive faster, thereby leading to less safe driving, but proximate computers also influenced participants to feel more engaged with the Driver's Assistant, thereby leading to safer driving behavior. The data analysis consisted of a path analysis to investigate the larger picture of how computer proximity affected safe driving behavior. It also consisted of standard analyses of variance (ANOVA) and *t*-tests in order to investigate isolated causal relationships. Participant experiences of engagement, discontentment, and information quality were measured by the online questionnaire (see Fig. 1). All driving behaviors were automatically measured by the driving simulator and verbal behaviors were collected from audio recordings of participants in the study, responding to the Driver's Assistant voice prompts. First, this section will discuss the larger path analysis of exactly how computer proximity affects safe driving performance. Second, this section will discuss isolated effects of computer proximity on driver disclosure and discontentment. Finally, this section will discuss the effect of perceived information quality on driver persuasion.

5.1. Computer distance effects on safe driving behavior

A path analysis of how computer proximity ultimately affected safe driving behavior followed two separate paths (see Fig. 2). Along the first path, drivers using the in-car Driver's Assistant drove faster ($\beta = 0.32$, $p < 0.05$); this, in turn, led to *less safe* driving behavior ($\beta = -0.37$, $p < 0.05$). However, along the second path, the in-car system led to greater engagement with the in-car system as compared to the wireless system ($\beta = 0.32$, $p < 0.05$); engagement led to *safer* driving behavior ($\beta = 0.35$, $p < 0.05$). Because these two separate paths counterbalance one another, they led to the non-significant direct relationship between computer proximity and safe driving, $F(1, 38) = 0.24$, $p = 0.63$. Note that fast driving and feelings of engagement are not significantly correlated, $r = -0.24$, $p > 0.13$.

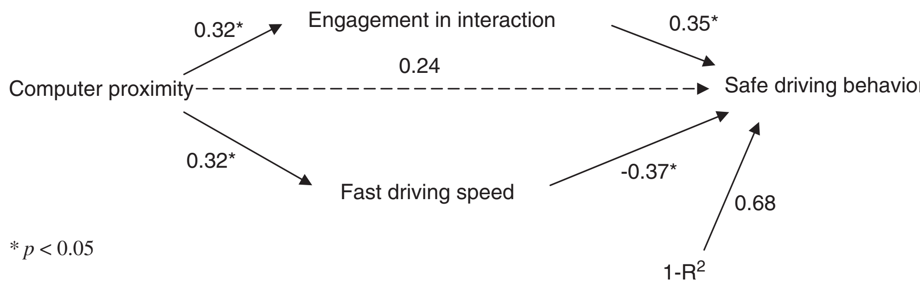


Fig. 2. Path model of computer proximity affecting safe driving behavior.

Table 2

Independent variables	β	t (35)
Path 1: *Multiple regression analysis of driving speed*		
Computer proximity	0.320	2.06[a]
Participant gender	−0.047	−0.30
DA voice gender	−0.235	−1.51
Course number	−0.021	−0.08

Note: $R^2_{adj} = 0.06$, $p<0.18$.
[a]$p<0.05$.

Table 3

Independent variables	β	t (35)
Path 2: *Multiple regression analysis of engagement*		
Computer proximity	0.316	2.07[a]
Participant gender	0.001	0.01
DA voice gender	−0.225	−1.47
Course number	0.177	1.16

Note: $R^2_{adj} = 0.09$, $p<0.13$.
[a]$p<0.05$.

Table 4
Multiple regression analysis of safe driving

Independent variables	β	t (31)
Speed of driving	−0.365	−2.42[a]
Engagement	0.354	2.32[a]
Participant gender	−0.005	−0.04
DA voice gender	−0.274	−1.83
Course number	−0.280	−1.91
Real speeding tickets	−0.238	−1.59

Note: $R^2_{adj} = 0.24$, $p<0.05$.
[a]$p<0.05$.

5.1.1. The first path: controlling for covariates

Along the first path, drivers using the in-car Driver's Assistant drove faster than those using the wireless Driver's Assistant, $\beta = 0.32$, $t(35) = 2.06$, $p<0.05$ (Table 2). Note that faster driving was an overall measure of how fast participants drove the course; this is different than how many times the driver actually broke the speed limit at any part of the course. Because the length of the course was held constant, lower measures of time on course indicated faster driving. While drivers were told they could choose their own routes (e.g., which road to take at intersections) the driving simulator used in the study automatically laid out the exact same programmed driving course (e.g., road types, towns, cities, rural areas, cars, pedestrians) in front of people who turned right, turned left, or went straight at any given intersection. The model of participant's real life speeding tickets, participant gender, Driver's Assistant voice gender, course type, driving speed, and engagement with the Driver's Assistant had a significant effect upon safe driving behavior, $adj\,R^2 = 0.24$, $F(6,31) = 2.89$, $p<0.05$, with speed of driving being the best predictor of safe driving behavior, $\beta = -0.37$, $t(31) = -2.42$, $p<0.05$ (Table 4). The covariates of participant's real life speeding tickets, Driver's Assistant voice gender, and course type were found to have no significant explanation of variance for unsafe driving behavior while driving speed and engagement did.

5.1.2. The second path: controlling for covariates

Drivers using the in-car Driver's Assistant felt more engaged with the system than those using the wireless Driver's Assistant, $\beta = 0.32$, $t(35) = 2.07$, $p<0.05$ (Table 3). Again, the model of participant's real life speeding tickets, participant gender, Driver's Assistant voice gender, course type, driving speed, and engagement had a significant effect upon safe driving behavior, $adj\,R^2 = 0.235$, $F(6,31) = 2.89$, $p<0.05$, with speed of driving being the best predictor of unsafe driving, and engagement being the only other significant predictor of safe driving behavior, $\beta = 0.35$, $t(31) = 2.32$, $p<0.05$ (Table 4).

5.2. Computer distance effects on disclosure and discontentment

5.2.1. Disclosure

Drivers disclosed more information about themselves with the in-car Driver's Assistant, $M = 52.9$ words per disclosure, $SD = 36.5$, than with the wireless Driver's Assistant, $M = 38.1$ words per disclosure, $SD = 18.9$, $t(36) = -2.10$, $p<0.05$. For example, in response to the disclosure-eliciting question, "What are your favorite kinds of foods?" a participant in the in-car condition responded, "Uh, the kind of food that I like. I look on the menu first and see if there's something I like, and make sure there's not something too expensive,'' whereas a participant in the wireless condition responded, ''Thai food, ice cream.''

5.2.2. Discontentment

Though perceived information quality was not significantly different between in-car and wireless Driver's Assistant systems, $F(1,38) = 0.26$, $p > 0.62$, it served as an important covariate in analyzing feelings of discontentment with the interaction. Drivers felt less discontentment with the in-car Driver's Assistant, $M = -0.84$, $SD = 4.72$, than the wireless one, $M = 2.55$, $SD = 6.57$, controlling for perceived information quality, $F(1,36) = 5.16$, $p < 0.05$.

5.3. Perceived information quality effects on persuasion

Though computer proximity did not directly predict how often drivers were persuaded by the Driver's Assistant, $F(1,36) = 0.68$, $p > 0.42$, perceived information quality did affect how much drivers were persuaded by the Driver's Assistant. The more positively the driver perceived the information quality, the more the driver was persuaded by the Driver's Assistant, $R^2 = 0.19$, $F(1,36) = 8.56$, $p < 0.01$.

6. Discussion

6.1. Computer distance matters

This study's finding supports the CASA paradigm (Reeves and Nass, 1996), extending the domain of source proximity effects from those of self-disclosure and impression management (Moon, 1998) in the text-based interviewing context, to those of attitudes, self-disclosure, and primary-task behaviors in a speech-based interface driving context.

The subtle and minimal manipulation of simply telling participants that the Driver's Assistant was proximate (in-car) or distant (wireless) not only affected attitudinal responses to the system, but remarkably affected driving behavior as well. Specifically, the belief that the driver was interacting with a proximate rather than distant system increased the amount of disclosure and initiated two processes that affect driving performance. In both conditions, participants were actually interacting with a computer in the driving simulator with no differences in speaker placement, sound volume, nor sound quality.

First, this study shows the mixed processes by which computer proximity affects safe driving behavior (Fig. 2). Drivers feel more engaged with the in-car system than the wireless one, which leads to safer driving behavior. However, drivers also drive faster while using the in-car system than the wireless one, which leads to less safe driving behavior. While these two effects led to no direct relationship between proximity and driving safety, they are important for understanding exactly how computer proximity affects driving behavior. Because the applied goal of this study is to improve driver safety, it is important for designers to know exactly how one might go about improving safe driving behavior. Because the effects of engagement and driving speed are not correlated, it may be possible for designers to change characteristics of these driver-computer interfaces to encourage engagement with the system and encourage drivers to drive more slowly, both of which would be efficacious for safety.

Secondly, drivers also disclosed more personal information to the Driver's Assistant when it was in-car rather than wireless. Unlike Moon's (1998) study, which found more disclosure and less impression management with more distant computers, this study's computer system did not ask questions that were quite as personal in nature as those in Moon's interviewing setting, which may explain the difference in effects.

Finally, drivers who used the in-car system generally felt more positively about the Driver's Assistant than those who used the wireless system, i.e., they felt more engaged and less discontent with the interaction. These findings are consistent with interpersonal studies of the associations between physical proximity and liking between people (Festinger et al., 1950).

6.2. Perceptions affect behaviors in driving

Perceptions of information quality were important predictors of behavioral responses to the Driver's Assistant. Those drivers who felt more positively about the system's information quality were more persuaded by the Driver's Assistant's suggestions. They took the advice of the Driver's Assistant more often, for example, by turning right when the Driver's Assistant suggested that the driver turn right. More specifically, the driver heard the Driver's Assistant's suggestion, ''To avoid the traffic congestion, you could turn right here to take a detour.'' If the driver felt more positively about the Driver's Assistant information quality, then the driver was more likely to actually turn right at the next intersection. Turning at intersections was an unusual behavior in this study; most drivers simply drove straight along the roads without turning even though they could have easily turned at any intersection on the course. Drivers also heard the Driver's Assistant suggest maneuvers such as, ''There is construction up ahead and the left lane will be closed. You could merge to the right lane now to avoid this barrier.'' Those who felt more positively about the system's information quality were more likely to merge from the left lane to the right lane before they were ever able to see the upcoming construction. In this very direct way, perceptions of information quality actually made drivers alter their particular paths through the driving course based upon suggestions made by the Driver's Assistant.

7. Limitations

One limitation of this study is the external validity of using a driving simulator. For the purposes of this study, the drawback of driving simulator studies did not outweigh the safety concerns for experimental participants. All participants were reminded to drive as they would with their own cars just before starting the experimental driving course. To encourage the feeling of realistic driving, the course was built to include various types of road conditions (see Section 4.2). In addition, all five pilot study participants indicated that the course felt very realistic. One key piece of evidence that participants did in fact treat the simulator as an actual driving task rather than a video game is that neither years of video game experience nor number of hours per week spent playing video games were associated with any of the measures, including the behavioral measures, in the study.

Another limitation in the current study is that we were only able to test a total of 16 persuasive voice prompts and 20 disclosure-eliciting voice prompts per participant. Each participant heard exactly half of each set of voice prompts; voice prompts sets were balanced across condition. The number of voice prompts used in the study was selected so that they would not overwhelm the driver with an excessively garrulous computer interface. It is possible that the content of these voice prompts altered responses to the Driver's Assistant, e.g., more persuasive prompts suggest that the driver slow down rather than speed up.

Because this was only one study that primarily focused on effects of perceived computer proximity upon driver behavior and attitudes, it did not explicitly test other potentially mediating variables that would be of use in future studies, including those of trust in systems (Lee and Moray, 1992; Lee and See, 2004; Muir, 1994; Muir and Moray, 1996; Parasuraman and Miller, 2004) and acceptance of them (Kantowitz et al., 1996, 1997). Another particularly relevant issue that this study did not directly address was that of situation awareness (Endsley, 1995; Smith and Hancock, 1995; Wickens, 1996) and how such additional information provided to drivers on the road will affect it; specifically, would in-car versus wireless systems differentially affect situation awareness?

8. Future work

This study of the effects of computer proximity on driver responses provides a provocative starting point from which to launch future studies of the psychological effects of distance. For example, the current study suggests a possible explanation for why both hand-held and hands-free cellular phone conversations are so harmful to driving safety as compared to conversations with a passenger. Specifically, regardless of the physical location of the voice interface, conversations via a cellular phone ultimately involve a distant conversational partner, which increase driver distraction from the road. To more explicitly test the first hypothesis proposed in Section 3.2 that talking with distant computers is more cognitively demanding than talking with proximate computers, one could either replicate the current study while also measuring cognitive load, or measure cognitive load and common ground maintenance for drivers talking with in-car passengers vs. remote callers (e.g., Shneider and Kiesler, 2005).

Alternatively, could a reduced sense of physical or social presence of both computer-based conversational interfaces (Lee, 2004) and human conversational partners increase driver distraction? To test the second hypothesis that proximate computers feel more present than distant computers, thereby increasing driver distraction, one could replicate the current study using additional measures of presence such as subjective reports along with behavioral and physiological responses as described by Lee (2004). It may also be that drivers feel less present in their own cars while talking with distant conversational partners than when they are talking with passengers in their cars.

This study also raises other questions of perceiving CASA. Would in-car (i.e., on-board) computers be more trusted concerning local information such as local climate and car maintenance, whereas distant computers would be more trusted about more global information such as navigational instructions and travel destinations? Likewise, would using different speaker locations inside the car influence perceptions of information content? For example, would navigation information coming from the passenger's side of the car be perceived as more credible than coming from the back of the car (i.e., a "backseat driver)? Would warnings about obstacles best be spoken from the corner of the car closest to the obstacle? Such content-based differences could be predicted by the CASA theory.

Of particular interest to those focused on driver safety are more carefully designed studies that focus on issues of risk in the driving context, particularly regarding dangers associated with even hands-free mobile phone use by drivers (e.g., Treffner and Barrett, 2004). Such information services provided in cars may provide information about upcoming situations on the road, but may also detract from the driver's performance on the road in the moment.

One could also extend this work to other contexts, other modalities of interaction, varying degrees of perceived proximity, etc. While this study is not a definitive answer to the question concerning perceived proximity of computer social actors, it breaks new ground for such investigations.

9. Implications for wireless system design

Although the physical placement and implementation of computer systems for driver interfaces (and other interfaces) may seem like a purely technical and back-end engineering issue, it must also be considered from the point of view of the end-user. This study has shown that perceived physical proximity to the user is important for not only self-disclosure and impression management (Moon, 1998), but also for engagement with the system and safe driving behavior.

Just as radio deejays often speak to listeners as if they were actually sitting in the same room, computer systems that are located far away from the car can present information as if they were inside the car itself. Providing such information services from in-car computers (or at least, presenting the information *as if* it were coming from in the car), will help to make users feel more positively toward interacting with the computer system. By designing the system to be engaging and to help drivers to avoid speeding (e.g., Kumar and Kim, 2005), in-car services may help drivers to drive more safely than those systems presented as wireless services.

Whether the system is built as an in-car computer or as a wirelessly communicating one, user perceptions of information quality are crucial. The better the user perceives the information quality to be, the more persuaded the user will be to take advice provided by the system. This finding suggests design considerations of ensuring that information quality lives up to *perceived* information quality. If the information provided merely *seems* to be of high quality, but actually is not, this may adversely affect driver performance, including driving safety.

Of course, it is entirely possible to not mention the location of the computer in relation to the user at all. Many web sites on the Internet do not explicitly state the physical location of the server on which they reside. However, in many cases, it becomes important for the user to understand where the communicative source is located. Radio stations intermittently mention their locations to listeners, providing context for their performances on air and allowing drivers to know why their sound quality decreases as they reach the outskirts of that radio station's city. Television news reporters often state their location as part of their introduction, letting viewers make inferences about their access to information about an event (i.e., first-hand vs. second-hand reports). Newspaper articles even come with their geographical location immediately beneath the headline title. As computer systems become more widely distributed around the world like radio stations, news reporters, and journalists, it is quite possible that it will become necessary for computers to disclose their physical locations as well.

10. Conclusion

This study demonstrates the ways that proximity of computer sources affects user perceptions and responses in ways that mirror perceptions and responses to proximity of human sources. People feel more engaged with proximate rather than distance computer sources. Computer proximity not only affects attitudes toward computer sources, but also affects safe driving behavior via two counter-balancing paths. These findings support the theoretical stance of conceptualizing computers as social actors. They also speak to safety issues concerning speech-based driver–computer interfaces. Once driver safety can be ensured, we can then move on to try to improve the driver/rider experience by providing helpful assistance, useful information, and pleasurable entertainment.

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Appendix A. Voice prompts

A.1. Computer distance voice prompts

In-Car (Proximal) Voice Prompts:

(1) This is the Driver's Assistant In-car System.
(2) Thank you for using the Driver's Assistant In-car System.
(3) You are using the Driver's Assistant In-car System.
(4) So that the In-car Driver's Assistant System may serve you better in the future, please answer the following question.
(5) This In-car Driver's Assistant System was created by Toyota.
(6) This information was brought to you by the In-car Driver's Assistant System.
(7) The In-car Driver's Assistant System has just been informed that…
(8) The In-car Driver's Assistant System is now loading.

Wireless (Distant) Voice Prompts:

(1) This is the Driver's Assistant Wireless System based in Chicago, Illinois.
(2) Thank you for using the Driver's Assistant Wireless System based in Chicago, Illinois.
(3) You are using the Driver's Assistant Wireless System based in Chicago, Illinois.
(4) So that the Wireless Driver's Assistant System may serve you better in the future, please answer the following question.
(5) This Wireless Driver's Assistant System was created by Toyota.
(6) This information was brought to you by the Wireless Driver's Assistant System.
(7) The Wireless Driver's Assistant System has just been informed that…
(8) You have tuned into the Wireless Driver's Assistant System based in Chicago, Illinois.

A.2. Persuasive voice prompts

(1) The upcoming hot dog stand attracts many tourists, creating heavy traffic in this area. To avoid the traffic congestion, you could turn right here to take a detour.
(2) The upcoming gas station has the cheapest prices of all stations within 20 miles along this highway. They are charging only $1.59 per gallon.
(3) There have been several pedestrian fatalities in this town recently. Watch out for pedestrians and jaywalkers.
(4) There is fog up ahead. You may want to slow down since there will be poor visibility.
(5) This town is known for its many bicyclists. You could merge to the left lane to avoid the bicyclists on the road.
(6) There have been six accidents on the upcoming curvy road in the past month. Slowing down may help you to compensate for the hazardous road conditions.
(7) There is a high wind advisory for the upcoming straight away of road.
(8) There is construction up ahead and the left lane will be closed. You could merge to the right lane now to avoid this barrier.
(9) This city has a lot of commuters and a high accident rate. You may want to slow down here.
(10) Cities of this size normally have populations of about 20 000. However, this particular city has only half of that because of a recent downturn in the local economy.
(11) In an attempt to discourage cruising, the city council decided to put in many stop lights on this road. You could take a detour by turning left here.
(12) The mountains in the distance rise up to 7000 feet above sea level. The current altitude of the car is 100 feet above sea level.
(13) There are a lot of police in the next town because of a recent increase in crime and car accidents there.
(14) There have been more than five accidents here in the last year as a result of drivers falling asleep at the wheel.
(15) Many of the people of this town work in the neighboring city so there may be commuter traffic coming up. It may be avoided by taking the next left.
(16) Because it is convenient to walk from place to place in this town, there are many pedestrians and few cars here. Beware of jaywalking pedestrians.
(17) There tend to be a lot of drivers out at this time of day; you might want to reduce your speed to 20 miles per hour.
(18) There is a very sharp turn ahead. Slowing down after the upcoming intersection will help you to get through the turn.
(19) A large parking lot is coming up on the right. Keep an eye out for cars pulling out of that parking lot and onto this street.
(20) There are reports of a large crowd of people gathering at the street ahead. To avoid the crowd, you may want to turn right here.

A.3. Disclosure eliciting voice prompts

(1) What kind of road conditions do you like best?
(2) Where is your favorite place to travel?
(3) What do you do in your free time?
(4) Do you usually drive alone or with passengers?
(5) What kinds of road conditions worry you most?
(6) What are your favorite kinds of foods?
(7) How much do you usually spend at a restaurant?
(8) Do you prefer malls or stores on an open street?
(9) What type of radio programs do you listen to?
(10) What types of music do you like?
(11) With what kinds of passengers do you prefer to drive?
(12) What do you look for in a good restaurant?
(13) What do you look for when deciding on where to fill up gas?
(14) What did you do last weekend?
(15) What are your plans for the upcoming weekend?
(16) What kinds of people do you like to drive with?

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