Skill Acquisition While Operating In-Vehicle Information Systems: Interface Design Determines the Level of Safety-Relevant Distractions

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Objective: This study tested whether the ease of learning to use human–machine interfaces of in-vehicle information systems (IVIS) can be assessed at standstill. **Background:** Assessing the attentional demand of IVIS should include an evaluation of ease of learning, because the use of IVIS at low skill levels may create safety-relevant distractions. **Method:** Skill acquisition in operating IVIS was quantified by fitting the power law of practice to training data sets collected in a driving study and at standstill. Participants practiced manual destination entry with two route guidance systems differing in cognitive demand. In Experiment 1, a sample of middle-aged participants was trained while steering routes of varying driving demands. In Experiment 2, another sample of middle-aged participants was trained at standstill. **Results:** In Experiment 1, display glance times were less affected by driving demands than by total task times and decreased at slightly higher speed-up rates (0.02 higher on average) than task times collected at standstill in Experiment 2. The system interface that minimized cognitive demand was operated more quickly and was easier to learn. Its system delays increased static task times, which still predicted 58% of variance in display glance times compared with even 76% for the second system. **Conclusion:** The ease of learning to use an IVIS interface and the decrease in attentional demand with training can be assessed at standstill. **Application:** Fitting the power law of practice to static task times yields parameters that predict display glance times while driving, which makes it possible to compare interfaces with regard to ease of learning.

INTRODUCTION

In the course of recent technological developments, the opportunities to engage in activities using information and communication systems while driving are increasing. For instance, the use of cell phones while driving is widespread, and route guidance systems provide well-received assistance in an increasing number of vehicles. But on the downside of gains in driver information and productivity are risks of driver distraction (e.g., Lee & Strayer, 2004; Recarte & Nunes, 2003; Srinivasan & Jovanis, 1997).

The main classes of possible driver distraction from in-vehicle information systems (IVIS) that are identified in the literature are visual distraction, cognitive distraction, and biomechanical interference (Tijerina, 2001). Manually entering a destination into a route guidance system or writing a text message on a cell phone are tasks that may take tens of seconds. Such extended intervals of time-shared visual attention can affect lateral vehicle control and hazard detection (e.g., Horberry, Anderson, Regan, Triggs, & Brown, 2006; Lee, Lee, & Boyle, 2007; Wierwille & Tijerina, 1998).

The time it takes to complete a task decreases with skill acquisition (Newell & Rosenbloom, 1981), and hence, the interval during which visual distraction, cognitive distraction, and

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biomechanical interference can occur and persist is shorter for skilled users. Furthermore, use of information technology by skilled operators is associated with less cognitive effort (Bainbridge & Quintanilla, 1989). Hence, skill acquisition and ease of learning are important factors to consider with regard to potential driver distraction. This applies to both IVIS interface design and IVIS assessment. Given the direct link between skill acquisition and reduced risk of distraction, surprisingly few studies of tasks performed with IVIS while driving address the issue of skill acquisition (Dingus et al., 1997; Nowakowski, Utsui, & Green, 2000; Shinar, Tractinsky, & Compton, 2005).

Our main objective in the present study is to demonstrate the importance of designing IVIS for ease of learning and to explore whether a common method for quantifying skill acquisition (fitting the power law of practice) is applicable for assessing on-the-market IVIS. Skill acquisition data were collected for a manual data entry task. The decrease in this task's visual demand when practiced while driving was compared with the decrease at standstill to see whether assessing visual demand would be possible without costly driving or simulator studies. Two clearly differing human–machine interfaces (HMIs) were employed. The respective exemplary data sets highlight elements of interface design that are important determinants of skill acquisition with IVIS.

The speed-up in task performance resulting from a fixed amount of practice diminishes with increased training. This characteristic diminishing effect of practice on task time can be described quantitatively with a power function (e.g., Ritter & Schooler, 2001). A simple version of the power law of practice relates task time (T) to the number of practice trials (N) as

$$T = A + BN^{-c},$$

where c specifies the rate with which practice decreases the task time from $A + B$ in the beginning to the asymptote A in the limit. The asymptote A is difficult to estimate unless training is studied for an extended period. For practical purposes, task times can also be fitted with the asymptote set to zero.

With the resulting two-parameter power function, task times are assumed to decrease from B in the beginning to zero in the limit at a rate of c:

$$T = BN^{-c}.$$

Recently, the power law of practice was challenged with skill acquisition data from simple experimental tasks that had a better fit with an exponential function (Heathcote, Brown, & Mewhort, 2000). However, for complex tasks, power functions capture training effects successfully (Lee & Anderson, 2001). Even if individual task times decrease discontinuously as a result of strategy shifts, task times averaged across individuals follow the power law (Haider & Frensch, 2002). Thus, the power law of practice fitted to skill acquisition data may be a valuable tool to quantify, compare, and evaluate IVIS with regard to ease of learning.

Acquiring skill in data entry and information search with IVIS involves learning how to operate controls and which information to attend to (Lee & Anderson, 2001). At the beginning of training, IVIS operation resembles problem solving (Bainbridge & Quintanilla, 1989). Declarative knowledge that may have been acquired through instructions or observations has to be held in working memory for the operator to figure out how to respond at a certain point in the interaction sequence (Anderson, 1982). Later in learning, when efficient procedures for standard operation have been established and attentional resources have been freed, this controlled and conscious processing of feedback and planning of actions become necessary again if unexpected feedback occurs as a result of nonstandard system behavior, user error, or system failure.

Of course, in interacting with information technology, the nature of the HMI affects skill acquisition. Easy-to-use and easy-to-learn HMIs are especially important for IVIS that are used while driving (Burnett, Summerskill, & Porter, 2004). When a driver uses an in-vehicle information system for the first time while driving, the level of skill in using the system is unclear and may be low. Drivers receive no special training in the use of IVIS and are not subjected to the selection criteria that apply for personnel in aviation and most other safety-critical domains. Thus, IVIS designers face the challenge of creating interfaces that can be used with minimal training, keep task times short, and do not create high cognitive demands. Furthermore, interface designers have to take into account the user's need to time-share focal vision with driving and that the driving task may demand full attention at any time, which would result in prolonged interruptions of the in-vehicle task (Baumann, Keinath, Krems, & Bengler, 2004; Gelau & Krems, 2004).

Because longer interruptions occur in more demanding driving conditions, total task time for the same in-vehicle task is prolonged at higher driving demands (Nowakowski et al., 2000). Consequently, total task time while driving is too variable to be useful as an indicator of task demands unless driving demands are controlled and standardized. Pure display glance time, however, is less affected by driving demands (Green, 1999). Hence, summed total display glance time is used to quantify the visual demand of in-vehicle tasks.

From an applied perspective, it is very attractive to estimate total display glance times while driving on the basis of total task times in a stationary vehicle or in the laboratory, because stationary task times can be obtained easily. However, stationary task time may be less predictive of total display glance time while driving after some training with the in-vehicle task; for example, if drivers learned to perform the in-vehicle task in part without averting their gaze from the road. Furthermore, driving is highly variable in attentional demand, and consequently, the relation between stationary task times and display glance times while driving may depend on driving demands. Hence, we studied skill acquisition under varying driving demands.

In Experiments 1 and 2, we collected training data sets for destination entry while driving and at standstill, respectively, with samples of middle-aged participants and two manually operated route guidance systems that differed in HMI design. The route guidance systems were selected with regard to a large expected difference in the ease of learning the HMIs.

EXPERIMENT 1: DRIVING STUDY

In the driving study, we trained two samples of drivers on route guidance systems with differing controls and differing dialogues for destination entry. Our objective in selecting the systems was to vary HMI features that we presumed to affect skill acquisition and to choose systems representative of advanced route guidance systems that were available on the market in Germany at the time of the study. In addition to varying the HMI, we studied the effect of driving demand on task times and on gaze behavior with three alternating driving conditions: *easy* (1.3 turns per kilometer), *easy following* (behind a leading vehicle), and *winding* (6.7 turns per kilometer).

Method

Participants. Six men and 6 women between 35 and 47 years of age ($M = 41.5$, $SD = 4.4$) drove an instrumented vehicle in reduced traffic. All had more than 10 years of driving experience ($M = 21.0$ years, $SD = 5.5$), and all had driven more than 100,000 km. All participants reported using computers at least 5 days a week ($M = 6.2$), had normal or corrected-to-normal vision, were not familiar with the experimental vehicle, and were paid for their participation. They were assigned to two groups consisting of 3 women and 3 men each. In the System A group, the mean age was 42.8 ($SD = 5.1$); in the System B group, the mean age was 40.0 ($SD = 3.5$).

HMIs. Each group used one of two customary route guidance systems. Both systems had similar-sized color displays but were operated differently. The main differences concerned manual controls and the destination entry procedure (schematic illustrations of the destination entry screens are shown in Figure 1). System A (Blaupunkt TravelPilot DX-N) is typical of add-on systems and was operated by keys on a remote control. Destinations were entered in a two-stage procedure consisting of spelling and list selection. System B (BMW Carin 520) was factory installed in the console and was operated mainly by a single dial and push button next to the display. System B partly automated alphanumeric destination entry by use of an intelligent speller as described later.

(For a comparison of the spelling procedures by means of the task analysis language NGOMSL, see Jahn, Keinath, Gelau, & Krems, 2003.) We expected that System B would be easier to learn and to operate while driving, which should be reflected in performance measures and in learning parameters obtained by fitting power functions.

The location of the systems' displays was approximately 50 cm to the right of and 30 cm below the normal forward line of sight. Each subtended approximately 5° of visual angle horizontally.

Destination entry tasks. Destinations consisted of a city name and a street name (for example, "Berlin, Scheinerweg"). In a series of tests, we selected 100 destinations that worked with both systems and grouped them into 25 sets of four destinations each. The sets required an approximately equal and constant number of entry steps for both systems. We composed six counterbalanced sequences of the 25 sets. Each destination was printed on a white card with city name and street name on separate lines.

Experimental circuit routes. The experiment was conducted on the Sachsenring racing track near Chemnitz, Germany. We opted for real driving in a controlled environment to achieve a tradeoff between external validity and ensuring safety (i.e., between a field study and simulated driving). Two circuit routes were prepared for the experiment, which were driven in both directions.

The easy circuit route was 1.5 km long and lay on the racing track. It required only one turn into a narrow passage and a turn back onto the racing track (1.3 turns per kilometer). This easy route was driven either without a leading vehicle (easy) or with a leading vehicle (easy following). Participants were instructed to keep a safe following distance and not to fall behind the leading vehicle.

The winding circuit route was 1.2 km long and encompassed parts of the racing track with narrow curves and single-track sideways and a narrow tunnel. On the winding route, we set up three stop signs in either direction at points where participants had to take turns and yield the right of way. There were eight turns in each direction on the winding route before which participants had to stop or reduce speed (6.7 turns per kilometer).

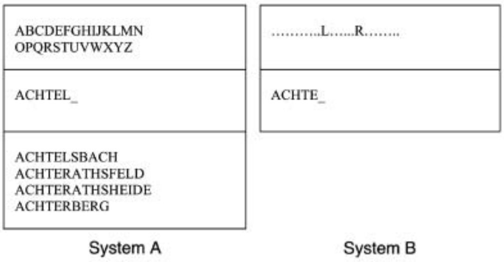

Figure 1. Schematic illustration of the route guidance systems' interface displays for alphanumeric destination entry. System A was operated with a remote control, System B with a single dial and push button.

The Sachsenring racing track is used for driver safety training and fuel conservation training. Traffic was low during experimental drives (about one vehicle in every third round on the winding route and in every sixth round on the easy route); however, participants had to expect other vehicles and pedestrians at any time.

Instruments. The experimental vehicle was a BMW 750iL with automatic transmission. It was instrumented for simultaneous recording of three video images. One camera view was on the driver from the front, a second view was on the display of the respective route guidance system, and the third view was forward on the traffic scene through the windshield.

To collect subjective ratings of workload, we used a German translation of the NASA Task Load Index (NASA-TLX; Hart & Staveland, 1988) without weighting of scales (the "raw" NASA-TLX; Byers, Bittner, & Hill, 1989). In addition, we prepared rating scales for situation awareness, usability rating scales (including a translation of the Short Usability Scale; Brooke, 1996), and a set of questionnaires on driving experience and technology use.

Procedure and design. Participants were informed that they were responsible for safe driving as in real traffic and that they should engage in the secondary destination entry task only if they thought it would be safe to do so. They were instructed to keep the speed at 40 to 50 km/h and to drive some warm-up laps.

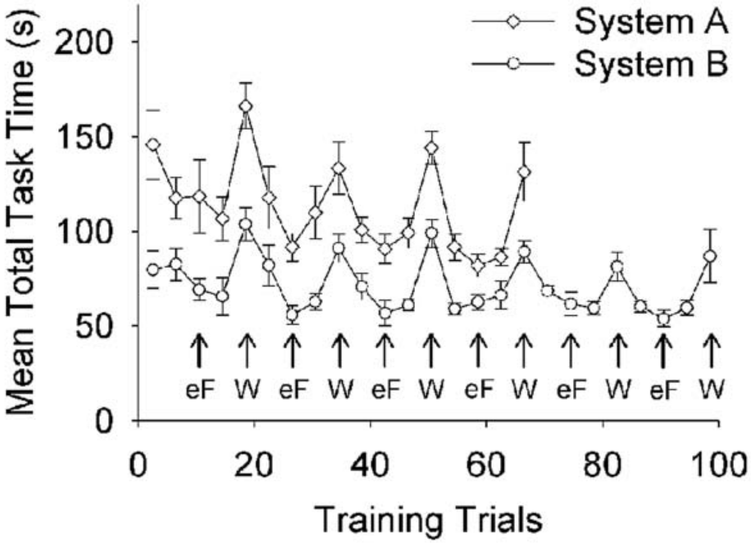

Figure 2. Mean total task times for sets of four destination entry trials in the driving study by system and driving condition. eF = easy following; W = winding. Error bars denote the standard error of the mean.

In the parked vehicle, the experimenter demonstrated destination entry twice and explained the procedure for error correction. Then the participant was instructed to enter two destinations and to try error correction with the second destination entry. At the beginning of the first block, the participant read the destination cards to be used in Block 1 aloud once. Next, the participant started driving on the easy circuit route, and the experimenter initiated the first destination entry trial. After eight trials on the easy circuit, participants performed four trials in the easy following condition. Four more trials on the easy circuit were performed and then four trials on the winding circuit route. At the end of the first block, each participant answered the NASA-TLX for the last four trials on the winding route and then gave situation awareness ratings for the entire block of trials.

The following blocks proceeded as in the first block, except that they started with only four trials on the easy circuit instead of eight (the sequence of sets of four trials in the easy, easy following, and winding conditions is shown in Figure 2). The direction in which the easy and winding circuits were driven varied between blocks. After every two blocks, the participant was given an extended break of 20 to 30 min. In the 6 hr that were scheduled for each participant, six blocks (100 trials) could be completed with System B. With System A, four blocks (68 trials) could be completed. After the last block, the participant filled out questionnaires on system usability, driving experience, and computer use. The experiment took 5.5 to 6 hr for each participant.

The HMI for destination entry was varied as a between-subjects factor (System A vs. System B). Route condition was varied within subjects. In the first block, the sequence of route conditions was easy, easy, easy following, easy, winding (5 × 4 trials); in the following blocks, the sequence was easy, easy following, easy, winding (4 × 4 trials).

Results

Driving performance. As noted earlier, participants were instructed to keep speed at 40 to 50 km/h on the easy circuit route. We computed the average speed per participant during destination entry trials on the easy route, excluding those trials during which participants steered through the narrow passage. The mean speed was 38.0 km/h (*SD* = 1.5) in the System A group and 39.3 km/h (*SD* = 2.2) in the System B group. There was only a slight increase in mean speed on the easy circuit across training. With System A, mean speed was 37.5 km/h (*SD* = 1.9) in

Block 1 and 38.4 km/h (*SD* = 1.2) in Block 4. With System B, mean speed was 38.2 km/h (*SD* = 3.9) in Block 1 and 40.5 km/h (*SD* = 3.2) in Block 6. These data confirm that participants adhered to speed instructions. We did not record lateral vehicle control, because the track was varied significantly in width, especially on the winding route, but we ensured, through instructions, that participants kept to the right side of the track.

Total task times. Means of total task times are plotted in Figure 2. The means were calculated for sets of four trials per participant and then were averaged across participants. The total task time was defined as the interval from the first to the last button press of a destination entry trial. Seven of the 1,008 trials were discarded as outliers (more than 4 *SD*s above the mean for the respective system, 0.69% of all data). To test effects of HMI and route condition after some training, we omitted Block 1 (Trials 1 through 20) and collapsed data across Blocks 2, 3, and 4 (Trials 21 through 68). The respective means of total task times are listed in Table 1, and corresponding ANOVA results are shown in Table 2.

As expected, mean total task times with System A (remote control) were longer than with System B (single dial and push button; $\eta^2 = 0.35$). Driving conditions also differed significantly ($\eta^2 = 0.36$). The interaction effect was not significant. Figure 2 shows increased total task times for destination entry trials in the winding driving condition (indicated by *W* in Figure 2) and slightly decreased total task times for easy following (indicated by *eF*) compared with easy trials, presumably because the leading vehicle provided sensitive feedback for vehicle control via peripheral vision during display glances. Post hoc tests with Tukey's HSD ($\alpha = .05$) confirmed the differences between winding and easy and between winding and easy following. The difference between the easy condition and the easy following condition was not significant. Total task times decreased with training; however, skill acquisition was more clearly reflected in summed display glance times.

Total display glance times. Participants' gaze behavior was manually coded from digitized video recordings with software support (Noldus Observer, Noldus Information Technology, Wageningen, Netherlands). We distinguished two glance categories. *Display glances* included glances to the system display, glances to the remote control of System A, and glances to the destination cards. *Driving glances* included the remaining glance intervals, in which participants' gaze was directed at the driving scene ahead, at mirrors, or at the instrument panel. The durations of display glance intervals during a destination entry were summed up to yield total display glance times. Again, means were calculated for sets of four trials per participant and then were averaged across participants. They are plotted in Figure 3.

Mean total display glance times in Blocks 2 through 4 (see Table 1) were longer for System A ($\eta^2 = 0.55$; see the ANOVA in Table 2). The main effect of driving condition was also significant ($\eta^2 = 0.03$); however, driving condition affected total display glance times less than it did total task times ($\eta^2 = 0.35$) and glance frequencies ($\eta^2 = 0.11$). Again, driving condition and system did not interact. All pairwise differences between driving conditions were confirmed by post hoc tests (Tukey's HSD). In the winding condition, total display glance times were longer than in the easy condition, and in both, total display glance times were longer than in the easy following condition.

Subjective ratings. At the end of each block after the four destination entry trials in the winding driving condition, drivers provided ratings of the workload that they had experienced during the winding trials on the six scales of the NASA-TLX. Mean ratings for each block are displayed in Figure 4 separately for each system. Ratings of Mental Demands, Temporal Demands, Effort, and Frustration were higher with System A (with effect sizes *d* in Block 1 of 2.08, 0.68, 0.51, and 0.99, respectively); however, only the difference in Mental Demands ratings was statistically significant (two-tailed *p* values in Blocks 1, 2, 3, and 4 of .01, .01, .07, and .09, respectively). Ratings on the scales Physical Demands and Own Performance were similar for the two systems (with *d* in Block 1 of 0.38 and 0.02, respectively).

The Mental Demands ratings for System A indicate that cognitive demand decreased with increasing skill. With System B, cognitive demand was rated lower even at the beginning of training. Apart from Mental Demands ratings for System A, the ratings only slightly decreased in the course of training.

Glance frequencies and glance durations. Durations of single display glances and single driving glances were manually coded from video recordings with a precision of 100 ms. The majority of display glances and the majority of driving glances were brief (approximately 1.5 s and 0.9 s, respectively), as is common for visually demanding in-vehicle tasks performed while driving. Although long single display glances were rare, their frequency is important with regard to safety considerations. The proportion of display glances longer than 5 s in Blocks 1 through 4 was 0.2% for System A (27 of 15,803 glances) and 0.1% for System B (13 of 11,776 glances). The proportions of display glances between 2.5 and 5 s in Blocks 1 through 4 for easy, easy following, and winding, respectively, were 9.3%, 8.3%, and 7.4% with System A and 6.6%, 7.3%, and 4.5% with System B.

Excluding glances longer than 5 s, we computed means for durations of single display and driving glances for each system and driving condition in Blocks 2 through 4 (see Table 1). Limited space precludes the report of detailed statistics for glance frequencies and durations of single display and driving glances. In brief, for neither of these variables did the factors system and driving condition interact significantly. For all, means in the winding condition were significantly higher than for easy and easy following. Only mean glance frequencies were significantly higher for System A and significantly lower in the easy following condition than in the easy condition (see Table 1).

Neither the frequencies of long glances nor mean glance durations showed training effects. The only statistically significant training effect was slightly increasing mean display glance durations in the winding condition with System B. Closer examination revealed that this training effect was restricted to three participants in the System B group. It most likely reflects increasing acquaintance with the winding route across the six training blocks with System B. Overall, mean display and driving glance durations of individual drivers were rather stable across training and across driving conditions.

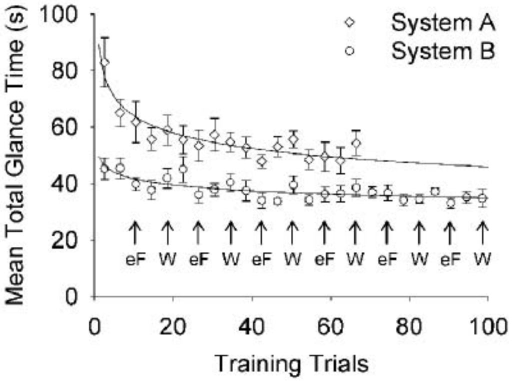

Figure 3. Mean total display glance times for sets of four destination entry trials in the driving study by system and driving condition with fitted power functions. eF = easy following; W = winding. Error bars denote the standard error of the mean.

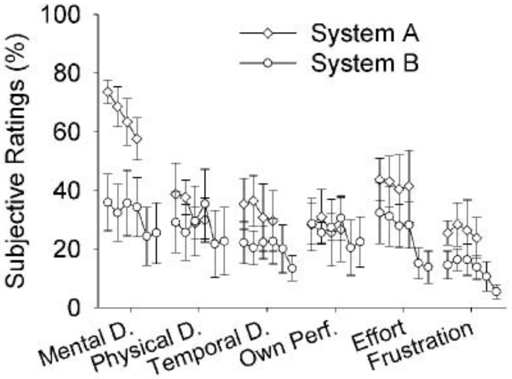

Figure 4. Means of subjective ratings of workload on the scales of the NASA Task Load Index (Mental Demands, Physical Demands, Temporal Demands, Own Performance, Effort, and Frustration) collected after each block for the destination entry trials performed in the winding driving condition in Experiment 1—that is, after Trials 20, 36, 52, and 68 for both systems and after Trials 84 and 100 for System B. Error bars denote the standard error of the mean.

Power law fits to total display glance times. Means of total display glance times shown in Figure 3 were affected less by changing driving conditions than were total task times. The winding driving condition prolonged mainly the time that drivers allocated to observing the road during a trial. Hence, the decrease in total

TABLE 1: Means and Standard Errors of Dependent Variables for Destination Entry Trials as a Function of Route Guidance System and Driving Condition (Blocks 2, 3, and 4)

	Experimental Condition					
	System A			System B		
Variable	Easy	Easy Following	Winding	Easy	Easy Following	Winding
Total task time (in seconds)						
M	100.81	87.92	136.32	67.05	58.44	93.12
SE	7.82	6.16	11.98	4.17	3.98	4.87
Total display glance time (in seconds)						
M	52.52	49.99	54.89	37.45	35.42	39.48
SE	3.29	3.78	3.20	2.22	2.20	2.48
Glance frequency						
M	35.2	33.3	39.0	26.8	25.1	30.5
SE	3.5	3.0	3.1	1.4	1.0	0.8
Duration of display glances (in milliseconds)						
M	1,540	1,540	1,430	1,410	1,430	1,290
SE	130	130	90	100	100	90
Duration of driving glances (in milliseconds)						
M	900	860	1,040	770	690	920
SE	70	90	110	60	60	60

TABLE 2: Results of 2 (Route Guidance System, Between) × 3 (Driving Condition, Within) Mixed Factorial ANOVAs of Mean Total Task Times and Mean Total Display Glance Times (Blocks 2, 3, and 4)

Source	*df*	*F*	*MSE*	η^2	*p*
Total task time					
System (S)	(1, 10)	16.90**	670.30	0.35	.002
Driving condition (D)	(2, 20)	48.97***	113.89	0.36	<.001
S × D	(2, 20)	1.30	113.89	0.01	.30
Total display glance time					
S	(1, 10)	14.51**	139.96	0.55	.003
D	(2, 20)	8.72**	6.91	0.03	.002
S × D	(2, 20)	0.08	6.91	<0.001	.93

$^*p < .05$. $^{**}p < .01$. $^{***}p < .001$.

display glance times with training reflects skill acquisition with the destination entry task.

To quantify the process of skill acquisition, we fitted power functions to means of total display glance times for System A and System B. The fitted power functions were of the two-parameter form $T = BN^{-c}$, where T is the total display glance time, B is the amount of time that is required at the beginning of training, N is the number of training trials, and c specifies the rate of speed-up with training. (With the two-parameter form of the power law, the asymptote is assumed to be zero; the variability of the data was too high to estimate the asymptote as a third parameter.) The best-fitting power functions are shown in Table 3 with root mean square error as an indicator of goodness of fit (e.g., Loftus, 2002). The corresponding plots are shown in Figure 3.

Both the display glance time required at the beginning of training (B) and the speed-up with training (c) were smaller for System B than for System A. These two parameters capture both main skill acquisition issues in comparing the system interfaces: that participants were faster with System B from the beginning and that with System A, total display glance times decreased more with practice, which indicates that participants had to learn more to use System A effectively.

Discussion

The visual demand of driving the winding course was reflected in total task times, glance frequencies, and glance durations. However, the display glance time necessary for entering a single destination with either system was nearly unaffected by varying driving conditions, as reflected in a still significant but much smaller effect size. Furthermore, display glance time decreased more smoothly across training. Hence, skill acquisition as indicated by decreasing total display glance times was not greatly impaired by visually demanding driving.

The reduction in total display glance times could be quantified by fitting parameters of the power law of practice; this was true for both system groups. The power law parameters clearly indicate the differences in ease of learning: The System B group required much less time for destination entry at the beginning of training, as indicated by an advantage of nearly 40 s in the B parameter. With System A, destination entry took longer throughout training, and drivers had to learn more before they could use System A effectively. The bigger change in total display glance times with a fixed amount of training is indicated by the higher c parameter for System A of 0.144, compared with 0.077 for System B.

These values are in the range of speed-up rates that were reported for learning to navigate on a display with different pointing devices (Card, English, & Burr, 1978). In this classic study, computer novices learned at speed-up rates of 0.13 with a mouse, 0.08 with a joystick, and 0.07 with step keys. After novices practiced, the mouse was found to be clearly superior. Today, it is harder to find mouse novices with whom one could study training from the beginning. This example illustrates that individual differences and prior training affect the estimates of learning parameters. Hence, the absolute estimates of learning parameters in Experiment 1 have to be taken with caution because they are based on data from a small sample of drivers. However, relative differences that were of interest were so large that they could be clearly confirmed with 6 participants per group and sufficient data from each participant. This finding pertains to the effect of driving conditions on task times, to the reduction of the effect of driving conditions when moving from task times to display glance times, and to the differences between systems.

The three interface features that were mainly responsible for the system difference were the controls (remote control vs. single dial and push button), the amount of information displayed (see Figure 1), and the demand that participants choose among alternative actions. With System A, alternative actions from which to choose were more numerous. Consequently, drivers in the System A group experienced a greater demand for controlled processing, especially at the beginning of training. With some experience, drivers became better at economically monitoring the four city or street names displayed on the entry screen to decide when to switch from spelling to selecting from the database. In contrast, with System B, each city or street name had to be spelled until it was completely disambiguated. Hence, there were no alternative actions in spelling.

Did our participants develop attentional skill while practicing destination entry while driving? For example, did they adjust the duration of display glances to accomplish entry steps, thereby avoiding gaze interruption and the need for reorienting on the display? Two results suggest they did not. First, individual glance patterns were rather stable across training, as indicated by mean display glance durations. These glance duration results are consistent with earlier evidence that individual glance patterns while time-sharing visual attention do not change without targeted training (Gopher, 1992). The second result suggesting that participants did not develop attentional skill is the fact that summed display glance times for System A were very similar to task times in the second experiment, in which the same tasks were trained in a stationary vehicle.

EXPERIMENT 2: TRAINING AT STANDSTILL AND TRANSFER

Our main objective in Experiment 2 was to obtain reference data to test whether skill acquisition and visual demand measured by summed display glance times while driving can be predicted by task times in a stationary vehicle. We trained a new sample of participants of equivalent age with the same systems and the same tasks. Each system group completed 100 training trials. Then each system group changed to the other system for an additional block of 20 transfer trials. We were interested in whether training on one system would produce positive or negative transfer for skill acquisition with the new system.

Method

Participants. Sixty individuals between 31 and 56 years of age (*M* = 45.4, *SD* = 6.4) served as paid participants. All held a valid driving license and reported more than 100,000 km driving experience. They were assigned to two groups matched for age. The System A group consisted of 8 women and 21 men with a mean age of 46.3 years (*SD* = 6.2), and the System B group consisted of 15 women and 16 men with a mean age of 44.6 years (*SD* = 6.4). Because of technical failure, 16 trials were not recorded on video (0.2% data loss).

Materials and procedure. In addition to the 100 destinations from the first experiment, 20 new destinations were constructed to study transfer. The transfer destinations were comparable to the training destinations with regard to the required entry steps for sets of four trials when used with System A and when used with System B. The system display was continuously recorded. After each block, subjective workload ratings were collected with the NASA-TLX. Usability rating scales and a questionnaire on experience with information technology were also administered.

The participant sat in the driver's seat of the parked vehicle, and the experimenter sat next to the participant in the front passenger seat. The demonstration and initial practice of destination entry proceeded as in Experiment 1. After 100 trials (six blocks), the participant rated the usability of the first system. Then the setup was changed to the second system, and the instruction procedure was repeated before the transfer block started. When the participant had completed the 20 transfer trials, workload ratings and usability ratings for the second system were collected. After each block, participants could take a rest.

The first four trials as well as the transfer trials were the same for all participants. The order of the remaining blocks of trials was balanced. Sessions with System A as the first system were longer than sessions that started with System B. Complete sessions took 3.5 to 4.5 hr per participant.

Results

Total task times. As in Experiment 1, total task times were manually coded from video recordings from the first to the last button press of a destination entry trial. Thirteen trials were discarded as outliers (more than 4 *SD*s above the mean for the respective system, 0.2% of all data). Mean total task times for sets of four trials averaged across participants and fitted power functions are shown in Figure 5. The parameter values of the fitted power functions are shown in Table 3.

As in the driving study, destination entry took longer with System A. Once the 20 trials in the first training block were omitted, mean total task times for data in the remaining blocks (2 to 6) were 58.34 s and 50.05 s for System A and System B, respectively (*SE*s = 2.14 and 0.92), $t(58) = 3.64$, p (two-tailed) $< .01$, $d = 0.94$. There was no significant main effect of gender and no interaction of gender with system, as confirmed in an ANOVA.

Transfer was nearly absent, as reflected in similar power functions for each system in the training and transfer intervals. Power function parameters for training and transfer were also similar to the power function parameters obtained for total display glance times in the

TABLE 3: Power Functions Fitted to Total Display Glance Times in the Driving Study (Experiment 1) and to Total Task Times (Experiment 2)

Variable	$T = BN^{-c}$	RMSE	Trials	Participants
Driving study (Experiment 1)				
System A	$T = 89.13N^{-.144}$	3.22	68	6
System B	$T = 49.76N^{-.077}$	2.32	100	6
At standstill (Experiment 2)				
System A	$T = 90.19N^{-.110}$	2.12	100	29
System B	$T = 63.13N^{-.057}$	1.36	100	31
Transfer (Experiment 2)				
System A	$T = 88.46N^{-.131}$	1.29	20	31
System B	$T = 60.32N^{-.058}$	1.48	20	28

Note. RMSE = root mean square error.

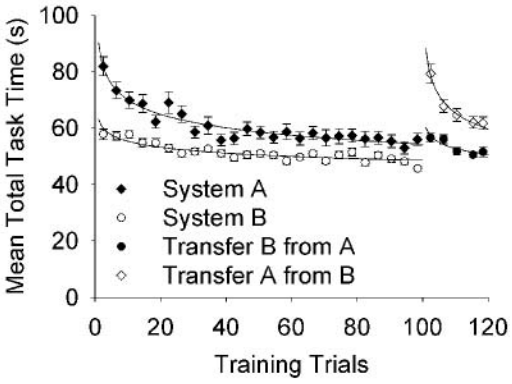

Figure 5. Mean total task times for sets of four destination entry trials at standstill in Experiment 2 by system and for the transfer training interval after the change of system with fitted power functions. Error bars denote the standard error of the mean.

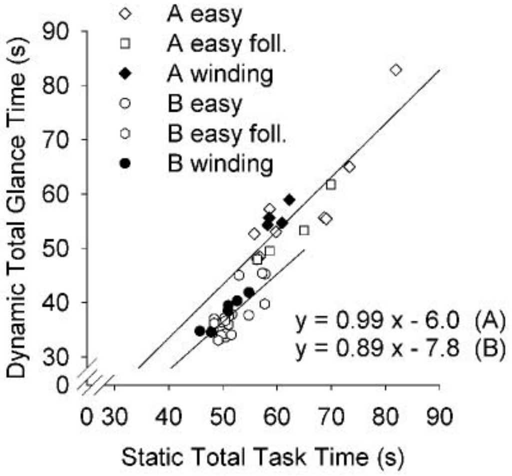

Figure 6. Mean total glance times in Experiment 1 (dynamic) for sets of four destination entry trials against the mean total task times in Experiment 2 (static) at the respective training interval with separate regression lines for System A and System B. Symbols indicate the conditions in Experiment 1. Filled symbols indicate the winding driving condition.

driving study. The speed-up rates obtained for display glance times were slightly higher than those for static task times (0.02 higher on average; see Table 3). The parameter indicating the time required at the beginning of training was almost the same as in the driving study for System A; for System B, it was increased. As in the driving study, with System A, task times were longer at the beginning of training, and decreased more with training, similarly in the training interval and in the transfer interval.

To see how well total task times at standstill predict display glance times while driving, the mean total task times were paired with mean total display glance times from Experiment 1 at the respective training level. These pairs are plotted in Figure 6 with static task times on the x-axis and display glance times from Experiment 1 on the y-axis. Linear regression equations were fitted for each system and indicate that static task times predict dynamic glance times with R^2 of .76 and .58 for System A and System B, respectively.

In sequential multiple regressions with driving condition entered in the first step, driving condition accounted for 5% and 7% of variance with System A and System B, respectively. Static task time entered in Step 2 was the only significant predictor. However, static task times were longer than dynamic glance times. Static task time overestimates dynamic glance time more for System B than for System A. For example, a static task time of 50 s corresponds to a dynamic glance time of 37 s with System B and 44 s with System A. As explained later, this is mainly attributable to system delays that slowed static performance.

Usability and workload ratings. Subjective ratings of workload with the NASA-TLX collected after each block showed only a slight tendency toward higher ratings for System A after Blocks 1 to 6 but significantly higher ratings for System A on all scales after the transfer block. After Block 1, mean ratings for both systems were lowest for Frustration (14.1 and 8.6 for Systems A and B, respectively) and highest for Mental Demands (30.9 and 24.4 for Systems A and B, respectively). Mean ratings decreased slightly with training and were still highest for Mental Demands after Block 6 (20.9 and 15.0 for Systems A and B, respectively).

After the transfer block, again, Mental Demands were rated highest for both systems (34.1 and 13.9 for Systems A and B, respectively). The lowest mean ratings were Physical Demands for System A (22.9) and Frustration for System B (6.5). All mean ratings after the transfer block were significantly higher for System A with effect sizes *d* of 1.32 for Mental Demands, 0.66 for Physical Demands, 1.22 for Temporal Demands, 1.92 for Own Performance, 1.53 for Effort, and 1.31 for Frustration.

Discussion

Experiment 2 demonstrated that power law parameters estimated from data collected in a stationary vehicle can yield reliable predictions for skill acquisition and visual demand while driving. Even with only 20 trials in the transfer block, estimated power law parameters reflected the characteristic system differences in ease of learning and demand. Absolute values of power function parameters from Experiment 1 have to be taken with caution because of the small sample size. Nonetheless, for System A, results from Experiments 1 and 2 corresponded nearly perfectly. For both systems, the speed-up rates obtained in the driving study were slightly higher than those for static task times.

The differences in power function parameters between the systems are again large; however, the difference in parameter *B* that indicates the time required at the beginning of training was around 27 s and thus smaller than the 40 s in Experiment 1. For System B, system delays induced longer task times and lowered the correspondence between display glance time while driving and total task times in a stationary vehicle.

Task times were longer than display glance times while driving with System B because of system delays. System B was busy calculating for up to approximately 2 s in response to character input because of the computations necessary for the intelligent speller. While participants were driving in Experiment 1, this idle time went, to a large extent, into driving glance time; however, it added fully to task time in Experiment 2. This upward shift of task times for System B did not preclude replicating the characteristic difference between the systems in learning rates.

Although static task times may overestimate dynamic glance times if system delays slow operation while at standstill, our results suggest that ease of learning for similar IVIS and the visual demand of performing IVIS tasks at varying skill levels can be evaluated without costly driving or simulator studies.

Learning rates were comparable in training and transfer for both systems; only parameter *B*, which corresponds to the task time at the beginning of training, was approximately 2 s lower in the transfer block for both systems. Hence, only slight positive transfer resulted from 100 trials of training on the system that was used first. This lack of transfer reflects the differences between the systems in controls, in displayed information, and in optimal monitoring procedures. The differences in controls alone may have been sufficient to prevent transfer, as results from laboratory studies suggest (e.g., Pashler & Baylis, 1991). Both greater positive transfer as well as negative transfer might occur between more similar systems, but in the present study, prior experience with one system did not interfere with the estimation of expressive power law parameters in the transfer block.

GENERAL DISCUSSION

Four main objectives guided our study of skill acquisition in performing a sequential data entry task—manual destination entry into a route guidance system—with two differing interfaces. We set out to explore whether task times and the visual demand of performing the data entry task while driving could be predicted from task times obtained in a stationary vehicle. Second, we were interested in quantifying the decrease in task times with practice and whether practice changed the correspondence between task times while driving and task times at standstill. Third, we compared performance and skill acquisition with two system interfaces that differed in controls and dialogue design to test predictions derived from an analysis of their demand profiles. Finally, transfer effects between the two systems were studied.

The answer to our first research question, concerning the predictive value of stationary task times, is a qualified yes. We obtained a close correspondence between total display glance times while driving, measured in Experiment 1, and task times in a stationary vehicle in Experiment 2. However, this correspondence in absolute values should be taken with caution because of the small sample size in Experiment 1.

For System A, display glance time and task time at standstill were nearly indentical. Static task time predicted 76% of the variance in display glance time. System A responded to user input with minimal delays. With System B, task times at standstill were increased by system delays that were absorbed into eyes-on-the-road intervals while driving. This reduced the relationship of static task times and display glance time to 58% explained variance. Nonetheless, the relative differences in ease of learning between the systems were clearly reflected in the power function parameters obtained from task times at standstill, which suggests that these parameters are useful as indicators for HMI comparisons.

The parameter B in the two-parameter form of the power law indicates the time required at the beginning of training; thus, the lower B is, the better. Parameter c indicates the speed-up rate. In the present study, System A had the higher speed-up rate because there was more to learn in operating its HMI. Despite the higher speed-up rate, task times remained higher than with System B throughout training. However, a high speed-up rate may be preferable if B is low.

The correspondence between display glance times and task times at standstill held across driving conditions. Increased driving demands elevated display glance times only slightly in Experiment 1; hence, a reasonable estimate of display glance time from task time at standstill seems possible without the need to discern driving conditions. This is good news for all who have to deal with the important task of evaluating the demands of IVIS HMIs and want to screen design alternatives for visual demand.

Notwithstanding the fact that our participants in Experiment 1 did not seem to acquire attentional or dual-task skill, practice effects were striking in all experiments, especially in interaction with system features. We deliberately chose systems that we expected to differ in ease of learning and opted for ecological validity in selecting route guidance systems that were on the market, in widespread use, and representative at the time of the study. The systems differed mainly in controls and dialogue design, and both these differences yielded more demanding destination entry with System A than with System B in terms of perceptual-motor coordination and supervisory control. Subjective ratings of workload confirmed our analyses of system demands. Both task times and mental demand are relevant for assessing potential safety problems arising from operating IVIS while driving. The more there is to learn in using a system, the longer these two safety-relevant variables change with practice.

One hundred trials of practice with one system did not result in transfer effects on task times with the other system. This confirmed that the systems differed clearly in those features that were important determinants of practice effects. Transfer is very likely between more similar systems (e.g., Singley & Anderson, 1989) and, for example, distorts system evaluation in within-subjects comparisons. Welcome from an applied perspective, the fact that we were able to estimate learning curves with just 20 trials in the transfer blocks of Experiment 2 illustrates that reliable power law parameters for averaged data can be obtained rather economically.

Our findings for operation at standstill may generalize to skill acquisition in using similar information technology. However, there are issues specific to in-vehicle tasks and some technological developments that should be considered to put our results in context.

We studied systems with two variants of manual control, but although they are representative, they do not exhaust the range of alternatives. Speech recognition for alphanumeric data entry has the potential to crucially reduce task times and visual demand (Tijerina, Johnston, Parmer, Winterbottom, & Goodman, 2000; Tsimhoni, Smith, & Green, 2004); however, procedural learning, cognitive control (Lee, Caven, Haake, & Brown, 2001), and some kind of visual feedback still seem to be necessary. Handwriting recognition is an alternative that also supports data entry using a well-established skill and promises some reduction in visual demand and task times (Burnett, Lomas, Mason, Porter, & Summerskill, 2005). But as with speech recognition, sufficient recognition accuracy is a prerequisite. Another alternative to minimizing the need to acquire new perceptual-motor procedures are touch screen interfaces with on-screen keyboards (Nowakowski et al., 2000; Tsimhoni et al., 2004), yet the visual demand of eye–hand coordination is high.

In some factory-installed route guidance systems, destination entry is inaccessible while the vehicle is in motion. Factory-installed systems and mobile devices with route guidance functions should at least provide warnings to drivers not to engage in potentially distracting entry dialogues (e.g., European Commission, 2007). At present, to our knowledge, no country prohibits entering destinations while driving, and with many systems, it is possible. Of course, our study is not intended to encourage destination entry while driving. We have chosen destination entry because it is a common example of a complex IVIS task. It involves alphanumeric data entry and information search, which are typical components of tasks performed with IVIS and mobile devices.

In the literature, there are differing reports on how successfully drivers ensure safe driving in scheduling concurrent in-vehicle tasks (Chiang, Brooks, & Weir, 2000; Cnossen, Meijman, & Rothengatter, 2004; Horrey & Simons, 2007; Tijerina et al., 2000). Without doubt, task characteristics, interface design, abilities, and skill level influence how well a driver can integrate an in-vehicle task with driving. Low task times, low visual demand, and interruptability are established design and evaluation criteria for IVIS (Jahn, Oehme, Krems, & Gelau, 2005; Johannson et al., 2005; Miyata & Norman, 1986). Our results clearly show that ease of learning is an important evaluation criterion as well.

We hope that we succeeded in highlighting demand for controlled processing and working memory load as critical dimensions of interface design for in-vehicle tasks that determine mental workload, the course of skill acquisition, and in turn, task times and visual demand.

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REFERENCES

Anderson, J. R. (1982). Acquisition of cognitive skill. *Psychological Review*, *89*, 369–406.

Bainbridge, L., & Quintanilla, R. (Eds.). (1989). *Developing skills with information technology*. Chichester, UK: Wiley.

Baumann, M., Keinath, A., Krems, J. F., & Bengler, K. (2004). Evaluation of in-vehicle HMI using occlusion techniques: Experimental results and practical implications. *Applied Ergonomics*, *35*, 197–205.

Brooke, J. (1996). SUS: A “quick and dirty” usability scale. In P. W. Jordan, B. Thomas, B. A. Weerdmeester, & I. L. McClelland (Eds.), *Usability evaluation in industry* (pp. 189–194). London: Taylor and Francis.

Burnett, G. E., Lomas, S. M., Mason, B., Porter, J. M., & Summerskill, S. J. (2005). Writing and driving: An assessment of handwriting recognition as a means of alphanumeric data entry in a driving context. *Advances in Transportation Studies an International Journal*, *2005 Special Issue*, 59–72.

Burnett, G. E., Summerskill, S. J., & Porter, J. M. (2004). On-the-move destination entry for vehicle navigation systems: Unsafe by any means? *Behaviour & Information Technology*, *23*, 265–272.

Byers, J. C., Bittner, A. C., & Hill, S. G. (1989). Traditional and raw task load index (TLX) correlations: Are paired comparisons necessary? In A. Mital (Ed.), *Advances in industrial ergonomics and safety* (pp. 481–485). London: Taylor and Francis.

Card, S. K., English, W. K., & Burr, B. (1978). Evaluation of mouse, rate controlled isometric joystick, step keys, and text keys for text selection on a CRT. *Ergonomics*, *21*, 601–613.

Chiang, D. P., Brooks, A. M., & Weir, D. H. (2000). *An experimental study of destination entry with an example automobile navigation system* (SAE Paper 2001-01-0810). Warrendale, PA: Society of Automotive Engineers.

Cnossen, F., Meijman, T., & Rothengatter, T. (2004). Adaptive strategy changes as a function of task demands: A study of car drivers. *Ergonomics*, *47*, 218–236.

Dingus, T. A., Hulse, M. C., Mollenhauer, M. A., Fleischman, R. N., McGehee, D. V., & Manakkal, N. (1997). Effects of age, system experience, and navigation technique on driving with an advanced traveler information system. *Human Factors*, *39*, 177–199.

European Commission. (2007). Commission recommendation of 22 December 2006 on safe and efficient in-vehicle information and communication systems: Update of the European Statement of Principles on Human Machine Interface. *Official Journal of the European Union*, *50 L32*, 200–241.

Gelau, C., & Krems, J. F. (2004). The occlusion technique: A procedure to assess the HMI of in-vehicle information and communication systems. *Applied Ergonomics*, *35*, 185–187.

Gopher, D. (1992). The skill of attention control: Acquisition and execution of attention strategies. In D. E. Meyer & S. Kornblum (Eds.), *Attention and performance XIV* (pp. 299–322). Mahwah, NJ: Lawrence Erlbaum.

Green, P. (1999). *Visual and task demands of driver information systems* (Technical Report UMTRI-98-16). Ann Arbor: University of Michigan, Transportation Research Institute.

Haider, H., & Frensch, P. A. (2002). Why aggregated learning follows the power law of practice when individual learning does not: Comment on Rickard (1997, 1999), Delaney et al. (1998), and Palmeri (1999). *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *28*, 392–406.

Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In P. A. Hancock & N. Meshkati (Eds.), *Human mental workload* (pp. 139–183). Amsterdam: Elsevier.

Heathcote, A., Brown, S., & Mewhort, D. J. K. (2000). The power law repealed: The case for an exponential law of practice. *Psychonomic Bulletin & Review*, *7*, 185–207.

Horberry, T., Anderson, J., Regan, M. A., Triggs, T. J., & Brown, J. (2006). Driver distraction: The effects of concurrent in-vehicle tasks, road environment complexity and age on driving performance. *Accident Analysis & Prevention*, *38*, 185–191.

Horrey, W. J., & Simons, D. J. (2007). Examining cognitive interference and adaptive safety behaviours in tactical vehicle control. *Ergonomics*, *50*, 1340–1350.

Jahn, G., Keinath, A., Gelau, C., & Krems, J. F. (2003). Destination entry while driving: The benefit of constrained options to act in multitask situations illustrated by two route guidance systems. In C. Stephanidis & J. Jacko (Eds.), *Human–computer interaction: Theory and practice* (Part 2, pp. 93–97). Mahwah, NJ: Lawrence Erlbaum.

Jahn, G., Oehme, A., Krems, J. F., & Gelau, C. (2005). Peripheral detection as a workload measure in driving: Effects of traffic complexity and route guidance system use in a driving study. *Transportation Research Part F*, *8*, 255–275.

Johannson, E., Engström, J., Cherri, C., Nodari, E., Toffetti, A., Schindhelm, R., et al. (2005). *Review of existing techniques and metrics for IVIS and ADAS assessment* (Deliverable No. D2.1.1). Adaptive Integrated Driver-vehicle Interface (AIDE) Consortium. Retrieved from http://www.aide-eu.org/pdf/sp2_deliv_new/aide_d2_2_1.pdf

Lee, J. D., Caven, B., Haake, S., & Brown, T. L. (2001). Speech-based interaction with in-vehicle computers: The effect of speech-based e-mail on drivers' attention to the road. *Human Factors*, *43*, 631–640.

Lee, J. D., & Strayer, D. L. (2004). Preface to the special section on driver distraction. *Human Factors*, *46*, 583–586.

Lee, F. J., & Anderson, J. R. (2001). Does learning a complex task have to be complex? A study in learning decomposition. *Cognitive Psychology*, *42*, 267–316.

Lee, Y. C., Lee, J. D., & Boyle, L. N. (2007). Visual attention in driving: The effects of cognitive load and visual disruption. *Human Factors*, *49*, 721–733.

Loftus, G. R. (2002). Analysis, interpretation, and visual presentation of experimental data. In H. Pashler & J. Wixted (Eds.), *Stevens' handbook of experimental psychology: Vol. 4. Methodology in experimental psychology* (3rd ed., pp. 339–390). New York: Wiley.

Miyata, Y., & Norman, D. A. (1986). Psychological issues in support of multiple activities. In D. A. Norman & S. W. Draper (Eds.), *User centered system design: New perspectives on human-computer interaction* (pp. 265–284). Mahwah, NJ: Lawrence Erlbaum.

Newell, A., & Rosenbloom, P. S. (1981). Mechanisms of skill acquisition and the law of practice. In J. R. Anderson (Ed.), *Cognitive skills and their acquisition* (pp. 1–55). Mahwah, NJ: Lawrence Erlbaum.

Nowakowski, C., Utsui, Y., & Green, P. (2000). *Navigation system destination entry: The effects of driver workload and input devices, and implications for SAE recommended practice* (Technical Report UMTRI-2000-20). Ann Arbor: University of Michigan, Transportation Research Institute.

Pashler, H., & Baylis, G. C. (1991). Procedural learning: 1. Locus of practice effects in speeded choice tasks. *Journal of Experimental Psychology: Learning, Memory and Cognition*, *17*, 20–32.

Recarte, M. A., & Nunes, L. M. (2003). Mental workload while driving: Effects on visual search, discrimination, and decision making. *Journal of Experimental Psychology: Applied*, *9*, 119–137.

Ritter, F. E., & Schooler, L. J. (2001). The learning curve. In N. J. Smelser & P. B. Baltes (Eds.) *International encyclopedia of the social and behavioral sciences* (pp. 8602–8605). Amsterdam: Pergamon. N. J. Smelser & P. B. Baltes (Eds.)

Shinar, D., Tractinsky, N., & Compton, R. (2005). Effects of practice, age, and task demands, on interference from a phone task while driving. *Accident Analysis & Prevention*, *37*, 315–326.

Singley, M. K., & Anderson, J. R. (1989). *Transfer of cognitive skill*. Cambridge, MA: Harvard University Press.

Srinivasan, R., & Jovanis, P. P. (1997). Effect of selected in-vehicle route guidance systems on driver reaction times. *Human Factors*, *39*, 200–215.

Tijerina, L. (2001). *Issues in the evaluation of driver distraction associated with in-vehicle information and telecommunications systems*. East Liberty, OH: Transportation Research Center.

Tijerina, L., Johnston, S., Parmer, E., Winterbottom, M. D., & Goodman, M. (2000). *Driver distraction with wireless telecommunications and route guidance systems* (Technical Report DOT HS 809-069). Washington, DC: National Highway Traffic Safety Administration.

Tsimhoni, O., Smith, D., & Green, P. (2004). Address entry while driving: Speech recognition versus a touch-screen keyboard. *Human Factors*, *46*, 600–610.

Wierwille, W. W., & Tijerina, L. (1998). Modelling the relationship between driver in-vehicle visual demands and accident occurrence. In A. G. Gale, I. D. Brown, C. M. Haslegrave, & S. Taylor (Eds.), *Vision in vehicles VI* (pp. 233–243). Amsterdam: North-Holland.

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