Presence and Quality of Navigational Landmarks: Effect on Driver Performance and Implications for Design

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Objective: The objective of this study was to investigate the impact of landmark information of varying quality within drivers' navigation instructions on driving and navigation performance when navigating an unfamiliar route. **Background:** Current vehicle navigation systems predominantly use distance-to-turn information to enable a driver to locate a forthcoming maneuver. Although it has been proposed that the design of driver navigation aids can be improved through the incorporation of landmarks as key navigation cues, little research has investigated how the quality of the landmark affects driver behavior. **Method:** An empirical field trial in a real traffic environment was undertaken with 48 participants in order to assess the effect of landmark quality on driver behavior when navigating an unfamiliar, complex, urban route. **Results:** The use of good landmarks (as opposed to poor landmarks or distance information) as key verbal navigation cues resulted in significant improvements in navigation performance, driving performance, and driver confidence immediately preceding a turn. The use of distance information to locate a turn resulted in significantly more glances to the in-vehicle display. **Conclusions:** Good landmarks offer significant safety and performance benefits to a driver navigating an unfamiliar route. Poor landmarks can result in driver performance worse than that obtained using distance to turn to locate forthcoming maneuvers. **Application:** The design of future vehicle navigation systems should not rely on distance-to turn information alone to enable a driver to locate forthcoming maneuvers but, rather, should incorporate good landmarks within the navigation instructions they present to drivers.

INTRODUCTION

Driver Navigation

One of the most demanding activities for drivers is navigating in an unfamiliar environment: Studies have long identified the difficulties that drivers have in planning and following efficient routes (King, 1986; Streeter & Vitello, 1986; Wierwille, Antin, Dingus, & Hulse, 1989). If drivers are unable to navigate successfully, there is a range of individual and societal consequences, including driver frustration and anxiety (Barrow, 1991) and reduced mobility for those groups wary of travel in unfamiliar environments (Burns, 1997). In addition, there are potential increases in congestion and pollution: King (1986) found in an empirical study in the United States that up to 20% of the miles driven could be considered "navigation waste." Jeffrey (1981) made a more conservative estimate, that 4% of travel in the United Kingdom falls into this category. (Note: The term *navigation* is used in this paper in preference to *wayfinding,* although *wayfinding* more accurately describes the dynamic step-by-step decision-making process [Passini, 1984] of a driver using a navigation system to reach a destination.)

Vehicle navigation systems (also termed *satellite navigation* or *route guidance systems*) offer a technological solution to aiding drivers' navigation and are increasingly a mainstream product in upper, midrange, and commercial categories of vehicles (Rowell, 2001). Typical systems use a combination of satellite GPS and digital map matching to calculate an optimum route to a

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specified destination. They then present a series of map overviews and turn-by-turn instructions to drivers, using a combination of auditory (verbal and nonverbal) and visual (text and graphics) information. A typical turn-by-turn instruction is an auditory "left turn in 300 meters," accompanied by a visual left turn arrow plus a distance-to-turn countdown bar that reduces to zero as a maneuver is approached.

Satellite navigation systems generally function extremely well (although of course they are wholly dependent on the completeness and accuracy of the underlying map database). However, from a human factors perspective, there are several potential limitations to their current design: Their concept is based around that of procedural, paced information presentation to the driver; they generally use distance information to enable a driver to locate a turn; and some systems employ complex visual human-machine interfaces (as well as corresponding auditory information). The potential of visual displays to distract drivers has long been recognized (Lunenfeld, 1989; Mollenhauer, Hulse, Dingus, Jahns, & Carney, 1997; Wierwille, 1993); this is potentially exacerbated with navigation systems, given their dynamic presentation of detailed information and their possible use within complex driving environments.

The Role of Landmarks in Navigation

It has been proposed that future navigation systems can be made more effective and safer by incorporating landmarks as key navigation cues (Burnett, 2000). Allen (1999) categorized human navigation into three basic forms – the *commute,* the *explore,* and the *quest* (the last defining navigation to an unfamiliar destination, as typically supported by a vehicle navigation system) – and highlighted the importance of landmarks in a piloting strategy for a quest: "Piloting involves landmark-based navigation…. A quest is often guided by route directions that consist of a listing of landmarks with actions designed to lead from one to another" (p. 555–556).

As well as being important for piloting strategies, landmarks are also key components in cognitive maps (Hirtle & Hudson, 1991; Hirtle & Jonides, 1985), which is the other main strategy identified by Allen (1999) for navigation to an unfamiliar destination. Trowbridge (1913) is recognized as the first to describe the prevalence of what he termed "imaginary maps" and described their role in the "readiness of man to be confused with respect to a new environment" (p. 892), underlining how these representations may be inaccurate representations of the real world. Tolman (1948) is considered the first to demonstrate empirically that animals (including humans) develop a spatial representation or "cognitive map" of their environment, which is used within spatial problem-solving activities such as navigation. Lynch (1960) also underlined the importance of landmarks in mental representations of a large-scale environment. In a series of influential studies, he found that environments could be categorized according to five element types: (a) paths, defined as the channels along which people move; (b) nodes, points where several paths meet (e.g., junctions); (c) landmarks, external reference points that are easily observable from a distance; (d) districts, the medium to large sections of an environment, which the observer mentally enters "inside of"; and (e) edges, linear elements that serve as boundaries between districts or other areas. Although more recent research has consistently demonstrated the importance of landmarks within cognitive maps, it has also shown how landmarks may also act as distorting elements within those maps (Holding, 1992; Sadalla, Burroughs, & Staplin, 1980).

Landmarks therefore support the strategies used to navigate to unfamiliar destinations. By providing external reference points that are easily remembered and recognized, they can potentially reduce the need to refer to an information display in order to locate a navigation decision point.

Definition of the Landmark Construct

Landmarks have been defined from varying theoretical perspectives. As previously stated, Lynch (1960) described them as external reference points that are easily observable from a distance. Kaplan (1976) defined a landmark as "a known place, a place for which the individual has a well-formed representation" (p. 42) and outlined two theoretical factors that lead to a place or object acquiring landmark status: the frequency of contact with the object or place and its distinctiveness. Three type of distinctiveness were hypothesized: visual distinctiveness (a predominantly objective quality relating to the physical attributes that discriminate it from the surrounding environment); inferred distinctiveness (knowledge concerning its structure or form that makes it stand out from what is usual); and functional distinctiveness (the salience in terms of the goals or subgoals of the individual). In addition to the visual characteristics of landmarks and their functional or social importance, the location of an object within the environment has also been shown to impact significantly on its effectiveness as a landmark (Allen, Siegel, & Rosinski, 1978; Carr & Schissler, 1969).

Several studies have commented on the characteristics of landmarks that are useful for navigation purposes. Akamatsu, Yoshioka, Imacho, Daimon, and Kawashima (1997) stated that popular landmarks in their study were visible from a distance, unique in appearance, and close to or part of the road infrastructure. Green, Levison, Paelke, and Serafin (1995) stated that the best landmarks are those that can be seen from a distance, are close to the road, near junctions, and permanent. Burnett, Smith, and May (2001) identified five attributes that were characteristic of “good” landmarks for vehicular navigation: permanence, visibility, usefulness of location, uniqueness (incorporating distinctiveness), and ability to be described with brevity.

For the purposes of this study, landmarks were broadly defined as external reference points that were potentially useful to a driver as navigation cues. Four main constructs were assumed to be key determinants of the effectiveness of a landmark as a navigation cue: its visibility to an approaching driver, its familiarity to a typical driver, its uniqueness in terms of being dissimilar to other nearby objects, and the usefulness of its location when being integrated within other environmental information in order to support navigation at driver decision points.

The Practical Benefits of Landmarks for Driver Navigation

The importance of landmarks in driver navigation has also been shown by a number of studies. Landmarks have been shown empirically to be widely used within drivers’ wayfinding strategies (Alm, 1990; May, Ross, & Bayer, 2003) and valued by drivers as information cues (Burns, 1997; Streeter & Vitello, 1986; Wochinger & Boehm-Davis, 1997).

The potential benefits of landmarks are relatively well established. A range of studies have empirically demonstrated how landmarks have the potential to enhance driver navigation systems in terms of (a) effective navigation decisions (Bengler, Haller, & Zimmer, 1994; Jackson, 1998; Tom & Denis, 2003), (b) reduced cognitive effort and distraction (Burnett, 1998), and (c) increased confidence and satisfaction (Alm, Nilsson, Jarmark, Savelid, & Hennings, 1992; Green, Hoekstra, Williams, Wen, & George, 1993). However, little, if any, research has been published that assesses the extent to which driver performance, within a real navigation context, is affected by the quality of the landmark – that is, the extent to which it is a “good” or “poor” navigational cue based on key physical and contextual factors.

Research Questions

The primary aim of this study was to investigate, within a real driving environment, the impact on driving and navigating performance of providing landmark information of varying quality within drivers’ navigation instructions. In particular, the study assessed (a) the potential benefits and drawbacks of using landmarks (as opposed to distance information) as the key auditory navigation information used to locate a forthcoming maneuver in an unfamiliar area; and (b) the impact of the “quality” of a landmark when drivers navigate and drive a complex, unfamiliar route. It was anticipated that providing good landmarks in verbal turn instructions would result in safer driving and better navigation performance than would providing either poor landmarks or distance-to-turn information. However, the extent to which performance would be degraded with the use of relatively poor landmarks was not evident. This study therefore provided empirical evidence that can be used to make informed decisions about the information to include as navigation cues in future vehicle navigation aids.

METHOD

Overview

This study comprised a road-based trial to assess driver navigation and driving performance with a modified vehicle navigation system that included landmarks within its instructions. Three different groups of participants used the navigation system to navigate around a complex urban route using navigation instructions that included "good" landmarks, "poor" landmarks, or distance information within the auditory information presented to a driver. A range of driver behavior measures were collected, including visual glance data, driving errors, driver workload, navigation errors, navigation confidence, and pre- and post-trial driver attitudinal responses.

Apparatus

A Land Rover Freelander™ was used that was fitted with a state-of-the-art, DVD-based satellite navigation system that provided visual and verbal turn instructions, as well as map overview information, to enable a driver to navigate to one or more specified destinations. On the driver's approach to each of the maneuvers en route, the satellite navigation system displayed a direction arrow integrated into a simplified junction overview, the name of the current road, and the name of the road being turned into; it also incorporated a distance countdown bar that showed the distance to the turn (starting at 500 m and counting down to 0 m in 50-m increments; Figure 1). In between maneuvers, the visual display presented a map overview to the driver.

In order to incorporate landmark information within the voice instructions, we recorded three sets of auditory prompts that included good landmarks, poor landmarks, or distance to turn information. The selection of "good" and "poor" landmarks was based on the assessment of a landmark's main attributes, discussed previously, that determine their suitability (quality in use) for navigation purposes: visibility, familiarity, uniqueness, and location.

With respect to the last three attributes, landmarks were selected that were all familiar and relatively permanent features of the built environment, unique such that they would not be confused with other instances of the same object, or other similar objects, and located at or within 20 m of the relevant junction. In addition, they were all common, easily recognizable objects such as petrol stations, as opposed to being unique objects such as individual restaurants, to prevent the need for memorization of new information cues. The differentiation between good and poor landmarks was based on the distance at which they

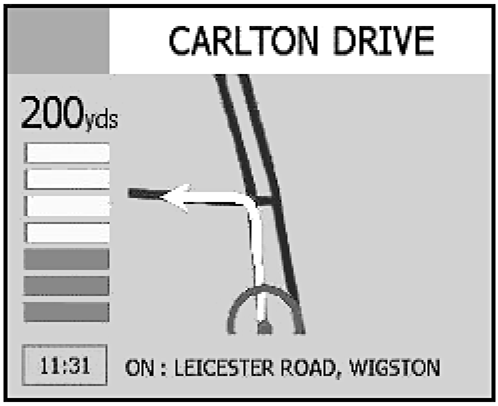

Figure 1. The visual information shown on approach to each maneuver. Each distance bar represents approximately 50 m (the system used yards); the bars empty from the bottom upward.

became visible and recognizable to an approaching driver on a clear day. This visible distance assessment was undertaken for each landmark independently by three raters with normal or corrected-to-normal eyesight while driving the route in fine weather, and the median rating from these assessments used. The good landmarks at the eight target maneuvers were visible at a mean distance of 212 m (SD = 83 m); the poor landmarks at those same target maneuvers were visible at a mean distance of 103 m (SD = 46 m). Typical good landmarks were traffic lights, pedestrian lights, and petrol stations. Typical poor landmarks were bus stops, post boxes, and phone boxes. These are listed in Table 1.

The auditory prompts were triggered and played to the driver, in lieu of the auditory output generated automatically by the navigation system, to enable participants to navigate the trial route. The messages consisted of up to three verbal prompts as follows: a Preview 1 message, given at the earlier of 500 m or the completion of a prior maneuver (this was omitted if subsequent maneuvers were closer than 300 m); a Preview 2 message, given at the earlier of 200 m or the completion of a prior maneuver; and a final auditory tone (beep) given at 50 m to the maneuver. This presentation strategy is typical of that employed by current vehicle navigation systems incorporating distance information. A typical auditory message that included a landmark was "turn right after the Texaco petrol station" (i.e., it included no distance-to-turn information).

To preserve face validity, where landmarks were present at incidental maneuvers, they were presented to the driver at these locations; however, these landmarks were not defined as "good" or "poor," and those data were not analyzed. Where landmarks were not present at incidental maneuvers, verbal distance-to-turn information was given for all participants. Visual distance-to-turn information was given for all participants at all maneuvers, as shown in Figure 1.

Participants

Forty-eight participants were recruited from the general public via Web notice boards, local newspaper advertisements, and posters. They were all over 21 years of age, had self-reported normal or corrected-to-normal vision, held a clean driving license, had driven regularly for at least 3 years, had not previously used a navigation system, and did not know the area where the study took place. A prescreening exercise enabled potential participants to be balanced for factors shown to potentially influence navigation performance, driving behavior, and/or information preferences: age (Burns, 1998; Walker, Alicandri, Sedney, & Roberts, 1991); gender (Burns, 1998; Ward, Newcombe, & Overton, 1986), and self-reported navigation ability (Allerton, 2000; Streeter & Vitello, 1986). In addition, participants were matched on self-reported distance judgment ability because this skill is fundamental in interpreting the distance countdown bar on the display and has been shown to vary considerably within the population (Fine & Kobrick, 1983) and to be negatively impacted by concurrent task demands (Böök & Gärling, 1980). Participants were then randomly allocated to one of the three between-subjects experimental conditions. They were paid £20 for their participation.

Experimental Route

An experimental route was chosen based around the south of Leicester, a city in the United Kingdom with approximately 320,000 inhabitants. It was explicitly designed to be navigationally challenging, having 37 driver decision points within its 17.5-km length. A driver decision point was defined as a location where a driver had more

TABLE 1: Summary of Maneuvers and Accompanying Landmarks

Maneuver	Good Landmark	Poor Landmark
Right turn off a dual carriageway	Traffic lights at the turn	A distinctive sculpture (height 3 m)
Right turn off a dual carriageway	Petrol station	Public house, terraced, set back 4 m from the carriageway
Left turn off a single carriageway	Pedestrian lights[a]	Bus stop
Left turn off a single carriageway	Public house, distinctive, detached	Bus stop
Left turn off a single carriageway	Pedestrian lights[a]	Post box
Right turn off a single carriageway	Pedestrian lights[a]	Bridge on the current road (to travel over)
Right turn off a single carriageway	Pedestrian lights[a]	Post box
Right turn off a single carriageway	Pedestrian lights[a]	Telephone box

[a] Appear similar to traffic lights.

than one navigation option and was not following a single major traffic flow, or where a driver potentially had to stop or give way to other traffic. In practice, these were geographical locations where a lack of navigation information could result in a navigation error or navigation uncertainty. The route was an urban/suburban route comprising 10% dual carriageway (two lanes in each direction) and 90% single carriageway (one lane in each direction). Approximately 75% of the route was among residential housing, and 25% was in urban (but not city center) retail and/or commercial districts. The route took approximately 40 min to drive, the speed limit on the majority of the route being 50 km/hr. The route was chosen on the basis of eight target maneuvers that met the following criteria: a left or right turn off the main route; other potential turns nearby (i.e., a requirement for information to precisely locate the maneuver); a good and a poor landmark that could be used to identify the turn; and, preferably, at least a 500-m approach to allow for the presentation of three auditory messages. The target maneuvers, plus accompanying good and poor landmarks, are summarized in Table 1.

There were an additional 25 maneuvers en route; these were incidental and served merely to link the target maneuvers into a continuous circuit. Participants were unaware that there were target and nontarget maneuvers.

Experimental Design

The experimental design was a 3 (information) × 8 (maneuver) mixed design. Information was a between-subjects factor representing the nature of the verbal information provided to a participant – that is, whether the auditory component of the navigation instructions incorporated (a) distance-to-turn information (as per current navigation systems), (b) good landmarks, or (c) poor landmarks (instead of distance information) to locate a turn. Maneuver was a within-subjects factor representing the eight target maneuvers en route, thereby enabling investigation of behavioral changes attributable to the variability of the characteristics of individual maneuvers. Given the constraints of driving an actual route with a real navigation system, it was not possible to randomize or balance the within-subjects factor, so all participants completed the target maneuvers in a set order. All trials took place midmorning or midafternoon (i.e., off-peak traffic conditions).

Dependent Variables

The data captured in the study measured driver safety, navigation performance, workload, driver confidence, and driver attitudes. Visual glance behavior was measured via video capture in order to determine the number and duration of glances to the in-vehicle visual display during the 500-m approach to each maneuver. The time that each participant spent moving and spent stationary (e.g., while sitting in traffic) was determined for each participant from the video analysis. The stationary glances (constituting less than 10% of the total) were not included in subsequent analysis, as their mean duration was 65% longer than the moving glances and some very long stationary glances were made (maximum 4.2 s). The percentage moving time metric was used to account for the speed variations in the approach to particular maneuvers; the total moving time, upon which this metric was based, was measured separately for each participant at each maneuver. Correspondingly, the percentage moving time metric was calculated as the total duration of the glances to the display while moving, divided by the total time spent moving during the approach to each maneuver.

Driving errors during the approach to each maneuver were assessed by a driving instructor, approved by the UK Driving Standards Agency, who accompanied each participant during the trial (and was unaware of the exact nature of the independent variable manipulation). Errors were recorded as minor, serious, or dangerous using a checklist developed in conjunction with the driving instructor. This employed six error categories as used in the UK driving examination: (a) use of mirrors and rear observation when signaling, changing direction, and changing speed; (b) appropriate use of signals (indicators); (c) response to signs and signals, including traffic signs, road markings, traffic lights, traffic controllers, and other road users; (d) performance at junctions, including speed of approach, observation, turning left or right, and cutting corners; (e) positioning in normal driving and lane discipline; and (f) awareness and planning.

Driving errors that participants committed were therefore recorded as minor, serious, or dangerous within these six error categories. A minor error was one that was not in itself potentially dangerous unless it was habitual. A serious driving error was one in which potential danger had occurred. A dangerous error was one involving actual danger to the driver, passenger, or other road users. These are exemplified in relation to a UK driver (driving on the left) turning right into a more minor road. If the driver turned early, cutting the corner without fully observing the road being turned into, and there were no parked vehicles or obstructions near the junction, it would be considered a minor driving fault. However, if the driver continued to turn right in this manner it would be considered habitual and therefore categorized as a serious driving fault. If there were parked cars close to the junction such that the driver had to brake and/or steer suddenly to avoid them, this would be considered serious in its own right. If the driver cut the corner and there was a moving car approaching the junction such that either one or both of the cars had to brake or steer suddenly to avoid a collision, this would be classified as a dangerous error.

All actual and "near" navigation errors were recorded. Near navigation errors were those in which a participant showed a clear intention (e.g., by a lane change or onset of indicators) to take an incorrect turn but subsequently corrected this and completed the maneuver correctly.

Driver workload was assessed on completion of the experimental route using a slightly modified version of the NASA TLX (Task Load Index), a subjective workload assessment tool originally developed by Hart and Staveland (1988). The modified version computes the Raw TLX (RTLX), an unweighted sum of the sub-scale values (the original version uses paired comparisons to derive weights for the sub-scales of the TLX). Byers, Bittner and Hill (1989) have shown that the RTLX scores can give an even better account of perceived workload than traditional TLX values. An additional sub-scale of "perceived distraction" was added to the RTLX as a result of the work of Fairclough (1991) to adapt the TLX for the driving task.

Driver confidence (after receiving each verbal instruction) was measured at approximately 450, 150, and 30 m from each target and nontarget maneuver by application of a simple verbal rating procedure in which the drivers assessed their confidence regarding the extent to which they knew where to turn *and* would be able to complete the maneuver successfully. After completing each maneuver, participants gave an additional confidence rating to indicate their confidence that they had taken a correct turn.

Drivers' beliefs and evaluative attitudes, and their temporal changes, were assessed using a three-part questionnaire based largely on 5-point agree/disagree Likert scale responses. This was administered pretrial, partway through, and posttrial. Because the focus of this paper is on driver performance, rather than attitude formation, these results are not reported.

Procedure

On arrival, participants were introduced to the study, signed consent forms, and completed Part 1 of the questionnaire. After familiarizing themselves with the vehicle controls, the participants completed a mixed-road familiarization drive lasting approximately 25 min. They then drove for about 10 min using the vehicle navigation system, receiving approximately eight navigation instructions during this period, and then undertook a practice session lasting a further 10 min in which they drove using the navigation system and gave confidence ratings at five maneuvers. All participants were able to complete this familiarization process successfully and without requesting additional practice time, which was offered in all cases.

After familiarization and training (lasting approximately 45 min), the participants drove the trial route using the navigation system with simulated auditory output, giving the three premaneuver confidence ratings and one postmaneuver confidence rating; they were occasionally prompted if necessary. During the approach to each maneuver, the nature and severity of any driving errors were recorded by the driving instructor, and navigation errors were recorded. Part 2 of the questionnaire was completed after 5 min of the test route. The participant then navigated the rest of the test route and completed the modified NASA-RTLX and Part 3 of the questionnaire before being debriefed and paid.

ANALYSIS AND RESULTS

Visual Behavior

Visual glance analysis was undertaken for the eight target maneuvers of interest. Figure 2 shows

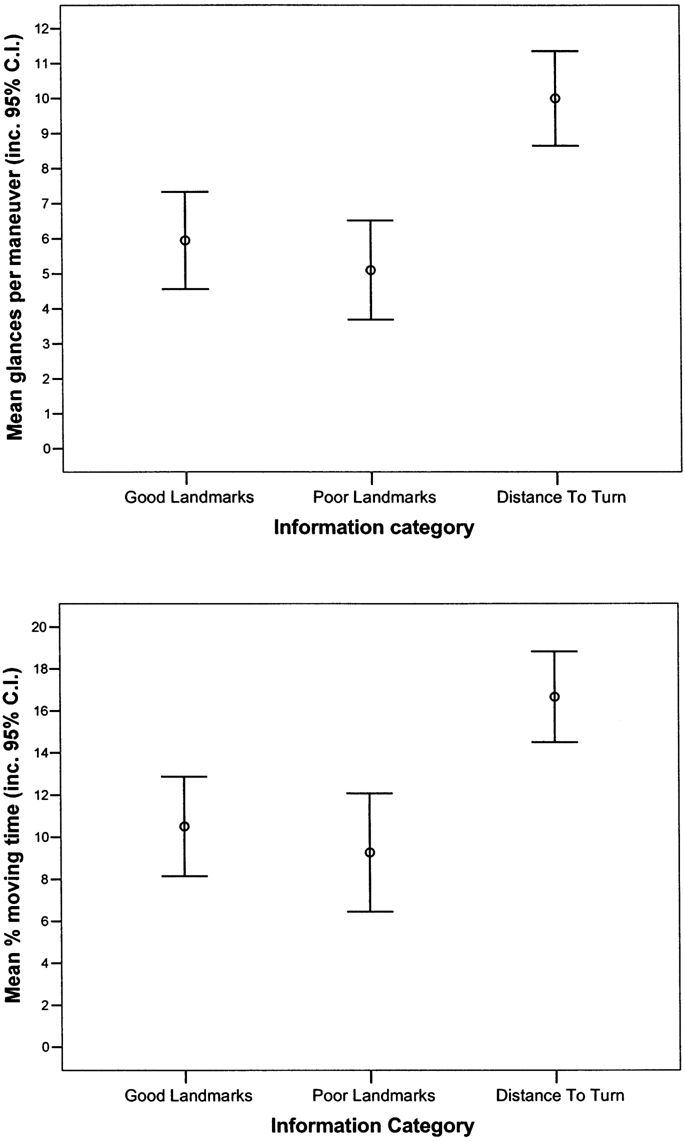

Figure 2. The effect of information category on (top panel) the mean number of glances made to the display and (bottom panel) percentage moving time spent glancing to the display during the approach to a maneuver (means: good landmarks: 5.9 glances/10.5%, poor landmarks: 5.1 glances/9.3%, distance information: 10.0 glances/16.7%). Error bars represent 95% confidence interval of the mean in all cases.

the mean number of glances to the navigation display while the driver was moving and the percentage moving time metric (total time spent glancing to the display while moving, as a percentage of the time spent moving) during the 500-m approach to a maneuver, according to whether participants used auditory navigation instructions employing good landmarks, poor landmarks, or distance information to locate a turn.

Each of these variables constituted a within-subjects component that represented the eight target maneuvers. The data for the within-subjects factor of maneuver showed nonsphericity; therefore a multivariate analysis of variance was used, analyzing all of the target maneuvers simultaneously (results are reported based on Wilks's lambda). (Similar results were obtained using a univariate repeated measures analysis with results adjusted for lack of sphericity by using the Huynh-Feldt epsilon correction.)

The information used to locate a maneuver (i.e., whether the auditory navigation instructions contained good landmarks, poor landmarks, or distance information) affected the mean number of glances made to the display during the approach to the maneuver, $F(4.135, 74) = 4.135$, $p < .001$, and the percentage of time that participants spent looking at the display during the approach to a maneuver, $F(16, 74) = 4.393$, $p < .001$, but had no impact on mean glance duration. Analysis of the eight individual target maneuvers indicated significant effects (at $p < .05$) of information category on the number of glances made to the display and the percentage moving time spent looking at the display for all eight target maneuvers, except the first one.

Tukey's honestly significant difference post hoc tests ($\alpha = .05$) showed that using distance information, compared with poor landmarks, to locate a turn resulted in a significantly greater number of glances being made to the display for seven out of the eight target maneuvers (and a marginal effect for the eighth) and, when compared with good landmarks, for five out of the eight target maneuvers. In one maneuver using good landmarks resulted in a greater number of glances than did using poor landmarks, and in another there was a similar marginal effect. For all other maneuvers, there were no differences between good and poor landmarks. Similar post hoc test results were achieved for the percentage moving time measure.

Driver Confidence

The empirical data consisted of four confidence ratings (low, medium, or high, coded as 1, 2, and 3, respectively) derived from three distinct points during the approach to each of the 33 maneuvers on route and from one point immediately after. Figure 3 shows the change in mean subjective confidence level across all eight target maneuvers, at each of the four confidence points, according to whether participants used good landmarks, poor landmarks, or distance information to locate the turn.

A Kruskal-Wallis test for three independent samples showed that the information used to locate a turn had a significant impact on the confidence of the driver at the Preview 1 point, $\chi^2(2) = 8.484$, $p = .014$, and the Preview 2 point, $\chi^2(2) = 8.049$, $p = .018$, a marginal impact at the final point, $\chi^2(2) = 5.856$, $p = .053$, but no impact on driver confidence postmaneuver. Multiple independent sample paired comparisons (Siegel & Castellan, 1988, p. 213; $\alpha = .05$) were undertaken to compare driver confidence at each of the confidence rating points, dependent on whether drivers used good landmarks, poor landmarks, or distance to locate a turn. At the Preview 1 and Preview 2 point, participants using distance were more confident than those using poor landmarks to locate a turn. At the final preview point, the good landmark group was marginally more confident than the poor landmark group. There were no other statistically significant differences, although Figure 3 indicates some potential trends in the data (note this figure shows mean confidence ratings, not mean ranking data).

Based on a Friedman test for three related samples, driver confidence increased during the approach to a maneuver for the participants using good landmarks, $N = 16$, $\chi^2(2) = 19.6$, $p < .001$, and poor landmarks, $N = 16$, $\chi^2(2) = 19.966$, $p < .001$, to locate a turn. There was no significant increase in confidence when using distance information to locate a turn.

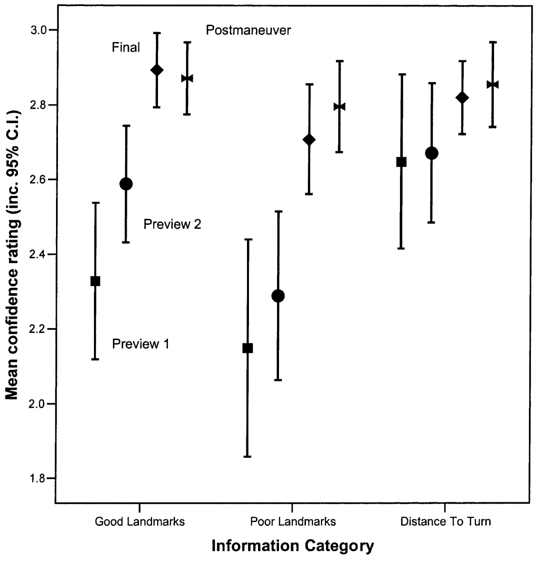

Figure 3. The effect of information category on the mean driver confidence (1 = low, 2 = medium, 3 = high) at the Preview 1, Preview 2, and final message points and at postmaneuver.

Driving Errors

In conjunction with the driving instructor, a coding scheme was devised whereby a score of 1 was assigned to each minor error a driver committed, a 5 to a serious error, and a 10 to a dangerous error. This was based on the pass/fail criteria for the UK driving test, plus the driver instructor assessment of habitual driving errors representing dangerous driving.

Driving errors were aggregated for each participant over all eight target maneuvers. Figure 4 shows, for each participant group, the contribution of each level of error to the total score, aggregated across target maneuvers, according to whether participants were using good landmarks, poor landmarks, or distance information to locate a turn.

A Kruskal-Wallis test for three independent samples showed that the information used to locate a turn had a significant impact on the total driving error scores, $\chi^2(2) = 7.337$, $p = .026$. Multiple independent sample paired comparisons (Siegel & Castellan, 1988, p. 213; $\alpha = .05$) indicated that participants using good landmarks produced a lower total driving error score than did those who used poor landmarks. An analysis of the minor, serious, and dangerous error scores showed that the information used to locate a turn had a significant impact on the serious error scores, $\chi^2(2) = 10.173$, $p = .006$), with no statistically significant differences for the minor or dangerous error categories.

An analysis was undertaken on each of the six individual driving error categories: observation, use of indicators, response to signs and signals, performance at junctions, vehicle positioning, and awareness and planning (described more fully in the Methods section). A significant effect was found for the indicator error score, $\chi^2(2) = 13.309$, $p = .001$; the multiple comparison technique described earlier indicated that participants using good landmarks achieved a significantly lower indicator error score than did those using poor landmarks and those using distance to locate a turn. No statistically significant differences were found for other driving error categories.

Driver Workload

The data from the NASA-RTLX constructs were combined with an equal weighting as per Nygren (1991). The information used to locate a turn made no difference to the perceived total driver workload.

Navigation Performance

Actual or near navigation errors were aggregated for each participant over all eight target maneuvers. Figure 5 shows these results, according to whether participants were using good land-

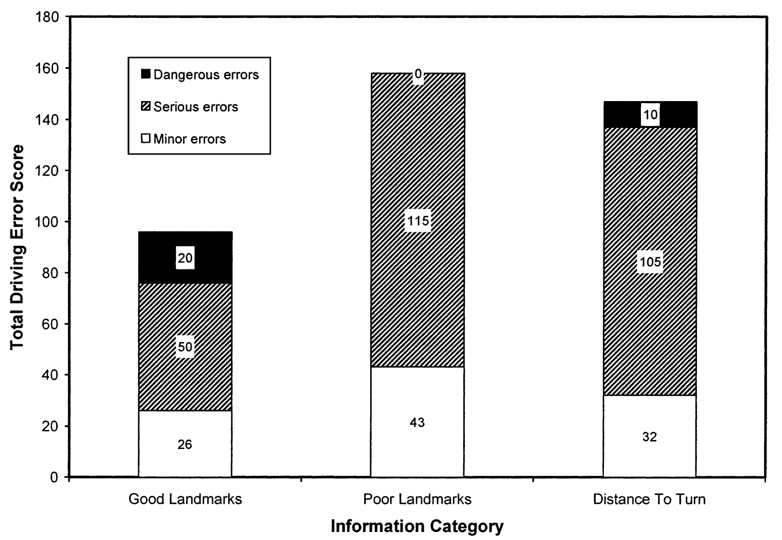

Figure 4. The effect of information category on the severity of errors and total driving error score per participant group (*N*s = 16, 16, 16).

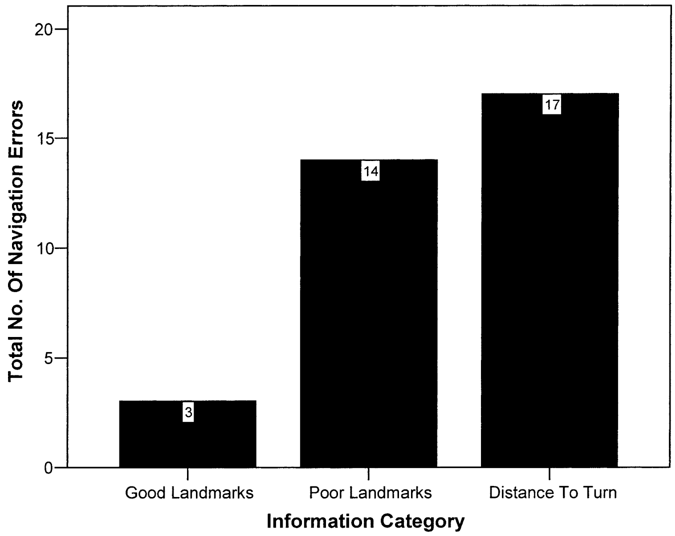

Figure 5. The effect of information category on the total of navigation errors made, per participant group.

marks, poor landmarks, or distance information to locate a turn.

A Kruskal-Wallis test for three independent samples showed that the information used to locate a turn had a significant impact on the number of navigation errors made, $\chi^2(2) = 18.749$, $p < .001$. The multiple paired comparison technique described by Siegel and Castellan (1988, p. 213; $\alpha = .05$) indicated that participants using good landmarks committed fewer (actual or near) navigation errors than did those using poor landmarks or distance information to locate a turn.

DISCUSSION

Visual Glance Behavior

Incorporating landmarks within the verbal navigation instructions resulted in a 40% decrease in the number of glances made to the display during the approach to the target maneuvers. This reduction in the number of glances while using landmarks was consistent with the results of Burnett (1998), who found that emphasizing landmarks (as opposed to distance) within a vehicle navigation system resulted in a reduction of glances during the approach to a maneuver from a mean of 5.0 to 1.6. A greater effect probably arose during the study by Burnett (1998) because landmarks in that study were represented on the visual display as well as being contained within the verbal instructions.

Within the present study, when landmark information was not available to the driver, frequent glances were made to the distance countdown bar in order to locate a turn. Where landmark information was provided within turn-by-turn instructions, it was apparent that participants used a range of strategies to locate a turn. Most participants made initial glances to the display when they received the first verbal instruction at about 500 m from the maneuver and then looked again at the display during the final approach to a maneuver. However, it was interesting that some participants made *no* glances to the display for particular maneuvers when using landmarks (compared with a minimum glance frequency of 4 when using distance), underlining the potential for navigation systems that place minimal reliance on provision of information via a visual display.

One of the most obvious indicators of the safety implications of an in-vehicle display is the total amount of time spent looking at that display. The right panel in Figure 2 shows that using landmarks (good and poor aggregated, and compared with distance) to locate a turn reduced the percentage of time spent looking at the in-vehicle display by approximately 40%, which was attributable to the reduction in the number of glances made to the display.

An interesting finding was that participants made a larger number of glances to the display when using good landmarks as opposed to poor landmarks to locate a turn. This could potentially question the definition of landmarks as "good" or "poor" because it indicates less eyes-on-road time for good external information cues as opposed to poor ones. However, because there was no visual representation of the landmarks on the visual display, a likely explanation for this unexpected result is that demand-driven (but resource-limited) visual search behavior resulted in participants directing greater visual attention to the roadside when searching for poor landmarks (good landmarks were easier to see), with subsequent reduction in attention to the visual display. In effect, because the display was not needed for those drivers using landmarks, participants searching for poor landmarks were too visually engaged with the external road scene to look at the visual display.

Visual glance behavior was differentially impacted at the target maneuvers according to the type of information presented to the driver. At five maneuvers there was an increase in the number of glances when using distance to locate the turn (as compared with using good or poor landmarks); at three maneuvers there was a reduction in the number of glances when using poor landmarks to locate the turn (as compared with using good landmarks or distance information). Although difficult to interpret with certainty, the relative increase in visual glances when using distance information occurred at those turns that were partially obscured and hence difficult to locate via visual search without reference to a landmark. In contrast, the reduction in glances with poor landmarks occurred at turns where the turn itself was relatively visible but the poor landmark was particularly difficult to locate, with greater exterior visual search being required (and hence a compensatory reduction in glances to the display). In practice the visual glance behavior and differential impact of information provision to the driver will be contextually dependent on a range of factors, such as the visibility of the maneuver, speed of traffic, drivers' expectations (of where the next maneuver is likely to be), and the nature and location of the landmark.

In this study, the visual component of the information provision was kept constant in order to prevent a confounding of the display-induced visual demand on the driver. However, this then resulted in an inconsistency of information display to the driver when using landmarks (visual distance and verbal landmarks). This is likely to have reduced the differential effect of the independent variable: A graphical representation of landmarks would have increased the ease of visually identifying the landmark and further reduced the need to refer to distance on the visual display. In reality, the visual complexity of a landmark-featured navigation system could be reduced, with a concomitant decrease in the visual demand induced by such a system.

Driver Confidence

Driver confidence during the initial stages (at approximately 450 m) of an approach to a maneuver was higher when good as opposed to poor landmarks were used to locate the turn but, in general, was lower than when distance information was used instead. This is shown in Figure 3, which also clearly shows the increase in confidence over the approach to a maneuver for good and poor landmarks and the comparison with the relatively stable confidence levels when using distance information.

Alm et al. (1992) have found landmarks to improve driver confidence regarding where to turn. However, the present study additionally investigated changes in confidence over the approach to a maneuver. Because of the urban driving environment (with complex road geometries, roadside furniture, parked cars, etc.), in most cases the landmark being used to locate a turn was not visible at the Preview 1 message point, which was typically given at 450 to 500 m from the maneuver (the average distance from the turn at which the good landmarks were visible was 212 m; for the poor landmarks, this was only 103 m). The type of information and the quality of any landmark used (as operationalized within this study) therefore appear to have a direct impact on a driver's confidence on approaching a maneuver. There was no differential impact postmaneuver: As long as the street name was present and visible, participants were able to use the visual display to confirm that they had taken the correct turn.

Driving Errors

The aggregated driving error scores showed that using auditory instructions employing good landmarks resulted in a significantly lower total error score than did using either poor landmarks or distance to locate a turn (Figure 4). Results regarding the inappropriate use of signals (i.e., turn indicators) are consistent with other studies that have looked at the effect on driving errors of including landmarks in navigation instructions (Bengler et al., 1994; Philips, 1999). No statistically significant differences were found for other driving error categories; however, the results suggest the potential safety benefits of using good landmarks to locate turns, because the highest score in each of the error categories always arose as a result of using either poor landmarks or distance to locate a turn. Analysis of the differences in error severity (i.e., minor, serious, or dangerous) contributing to the overall error score indicated that it was the error score arising from serious errors which differed according to the information presented to the driver. This suggests that differences in the total error score were not attributable merely to differing driving styles (e.g., braking late for maneuvers or rarely using turn indicators), as this would have resulted in disproportionate errors within the minor error category.

Driver Workload

The results for perceived driver workload failed to detect any differences according to whether drivers were using good landmarks, poor landmarks, or distance information to locate a turn. The NASA-RTLX has been successfully employed within driving research to demonstrate effects attributable to a range of independent variables, such as form or modality of information presentation (Lee, Caven, Haake, & Brown, 2001), and early navigation studies (e.g., Alm et al., 1992) have shown that drivers' mental workload was lower when landmarks were included in navigation instructions. There are several potential explanations as to why no differences in driver workload were detected in this study: (a) To ensure face validity, a manipulation of the independent variable (and therefore expected differences in workload) occurred only at those maneuvers where landmarks were present, whereas the NASA-RTLX was completed at the end of the route, taking into account all maneuvers. (b) Unlike previous studies, in this study the visual information was held constant across the independent variable manipulation, and therefore the variation in cognitive demand arising from the independent variable was likely to be less. (c) Any minor effects on workload were likely to be masked by isolated traffic incidents attributable to the situated context of the study (i.e., on a public road with uncontrollable traffic conditions). It was likely that the verbal confidence rating process that the drivers undertook at each maneuver increased their mental workload, in addition to the navigation task they were undertaking. Although this was a potential confounding factor, there was no reason this should have differentially impacted any one of the participant groups.

Navigation Errors

Participants using good landmarks made far fewer (actual or near) navigation errors than did those using either poor landmarks or distance information to locate a maneuver, as can be seen in Figure 5. Taking into account the total number of target maneuvers undertaken (i.e., those maneuvers for which a distinction was made between landmarks and distance information), the percentages of navigational errors made were 2% for good landmarks, 11% for poor landmarks, and 13% for distance information. The potential navigation benefit of good landmarks mirrors the results of other studies, including Alm et al. (1992) and Bengler et al. (1994), although those studies did not explicitly differentiate between good and poor landmarks. In practice, the absolute error rates reported in this study are unlikely to be as high within a real-use context, given that the experimental route employed was deliberately chosen to be challenging and participants were chosen who had no prior experience of using navigation systems (they were therefore more representative of first-time rather than experienced navigation system users).

Limitations to the Study

There were several potential limitations to the study. This road study suffered from the typical lack of control over potentially confounding factors and from the usual limitations of a cross-sectional, rather than longitudinal, design. However, the mixed design enabled temporal changes in the dependent variables to be identified, and these are reported where appropriate. The main threats to reliability and validity arise from the multipliers used within the driving error score assessments and from the individual interpretation of the driver confidence construct (it could be argued that this actually represented an overall "well-being" rating). However, the driver error results are consistent with the earlier research discussed previously. In addition, the impact of the information category on driver confidence has intrastudy consistency with the landmark visibility and participant attitudinal data (which were not reported because the focus of this paper was the behavioral impact of including landmarks within navigation instructions).

The study incorporated several key balancing variables in order to match participants across the main between-subjects factor (whether they received good landmarks, poor landmarks, or distance information in the verbal instructions). This increased the confidence in the analysis of the impact of the main independent variable. However, the balancing variables of navigation ability and distance judgment were only self-reported, so they were not analyzed as independent variables in their own right. It is recommended that future studies of this nature objectively quantify these variables in order to assess their impact on driving and navigational performance.

SUMMARY AND CONCLUSIONS

The main findings arising from this road study were that when good landmarks (as opposed to poor landmarks or distance information) were used to locate forthcoming maneuvers, navigation performance, driving performance, and driver confidence immediately preceding (e.g., 30 m from) a turn were all increased. The use of distance information (as compared with landmarks in general) resulted in the greatest reliance on an in-vehicle display but also in the highest driver confidence during the early stages of an approach (e.g., from 450 to 200 m) to a maneuver. The use of poor landmarks resulted in the lowest driver confidence at this point. The information used to locate a maneuver had no impact on subjective driver workload or postmaneuver confidence.

The chief design recommendation that arises from this study is that navigation systems be developed that do not require a driver to use distance-to-turn information to locate a forthcoming maneuver. A hybrid approach may be most beneficial, in which distance-to-turn information is used to create initial driver confidence and good landmarks are used when they become clearly visible. Although landmarks are a natural component within human navigation strategies, they will be beneficial only if they are good landmarks, taking into account their visual characteristics, the perception of them by potential users, their location in relation to the road network, and the physical properties of the built and traffic environment, such that drivers can see, recognize, and use them as navigation cues.

Although the potential benefits of landmarks have been demonstrated, several fundamental issues must be addressed before they can be successfully incorporated within next-generation navigation systems: (a) The first issue concerns the concepts that future navigation systems should employ – for instance, whether future navigation systems should be based on proceduralized turn-by-turn instructions or on a dynamic, resource-managing "travel assistant" that increases the context-dependent relevance (and hence added value) of information. Future systems could adapt to the availability of particular navigation cues, such as landmarks and direction signs, and tailor the delivery of navigation instructions based on the need for explicit new instructions at driver decision points. A future navigation system could therefore use a combination of turn-by-turn instructions, which may include landmarks as key locators, as well as using a less paced delivery of navigation instructions based on following road signs, where routes or sections of routes are clearly signposted. In this latter case, landmarks may be relatively superfluous. (b) The second issue concerns the implementation of such context-dependent systems – for example, how the factors relating to context of use and information quality are measured or predicted and how these are incorporated into system algorithms. (c) The third issue concerns the content, depth, and accuracy of information that is needed in navigable map databases in order to present landmarks to drivers, as well as the implications for collating, maintaining, and enhancing this data.

This study has shown that although incorporating landmarks within navigation systems can enhance a driver's safety and navigation performance, a key prerequisite is to distinguish between good and poor landmarks. The incorporation of poor landmarks within navigation systems is likely to be worse than not using them at all.

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