An evaluation of alternative Do Not Enter signs: failures of attention

Nancy E. Laurie a,1, Shuping Zhang a,2, Ravi Mundoli b,3, Susan A. Duffy c, John Collura d, Donald L. Fisher e,*

a Department of Mechanical and Industrial Engineering, University of Massachusetts, Amherst, MA 01003, USA
b Department of Civil and Environmental Engineering, University of Massachusetts, Amherst, MA 01003, USA
c Psychology Department, University of Massachusetts, Amherst, MA 01003, USA
d Department of Civil and Environmental Engineering, University of Massachusetts, Amherst, MA 01003, USA
e Department of Mechanical and Industrial Engineering, University of Massachusetts, Amherst, MA 01003, USA

Received 12 May 2004; accepted 14 July 2004

Abstract

Drivers who make wrong-way entries onto highway exit ramps or restricted roads are at serious risk of injuring themselves or others. One cause of these wrong-way entries may be the actual signage itself. A good sign in this context should draw attention to itself and then convey its message as quickly and clearly as possible. However, the existence of wrong-way entries suggests that this is not always happening with the recommended two-dimensional Do Not Enter plus One-Way sign that is currently posted at most exit ramp terminals. Several alternative Do Not Enter signs were evaluated on the University of Massachusetts driving simulator, signs which based on a preliminary evaluation should better draw attention to themselves and more quickly convey their message. The alternative signs included both a three-dimensional Do Not Enter sign and a combined One-Way plus No Right Turn sign (without the usual symbology). Participants noticed more wrong-way entries when exit ramp terminals were posted with the combined One-Way plus No Right Turn sign than when they were posted with all other alternatives, though this difference was only marginally significant when compared with the standard two-dimensional Do Not Enter plus

* Corresponding author. Tel.: +1 413 3740966; fax: +1 413 5451027.
E-mail address: fisher@ecs.umass.edu (D.L. Fisher).
1 Nancy Laurie is now at Eastman Kodak Company.
2 Shuping Zhang is now at Simplex.
3 Ravi Mundoli is now at University of California, Berkeley.

1369-8478/$ - see front matter © 2004 Published by Elsevier Ltd.
One-Way sign. These results were consistent with multiple resource theory, which assumes different resource pools are used to process verbal and spatial information.

© 2004 Published by Elsevier Ltd.

Keywords: Driving simulator; Regulatory signing; Multiple resource theory

1. Introduction

Wrong-way entries can too often end in tragedy. The signing used to prohibit such entries is perhaps most critical at throughway exit ramp terminals. The Manual on Uniform Traffic Control Devices (Federal Highway Administration, 2003) indicates that both One-Way and two-dimensional (2D) Do Not Enter signs should be posted at these terminals. However, in many cases the exit ramp terminals are posted only with 2D Do Not Enter signs which frequently are turned to face drivers who would be making a left across traffic (Fig. 1, left side). This makes it all but impossible for drivers approaching a highway exit ramp on the right-hand side to notice that the ramp is indeed a restricted one before they make a wrong-way entry (Fig. 1, right side). Accidents currently occur with either type of signing and remain of ongoing concern to both states (Cooner, Cothron, & Ranft, 2004) and the federal government (Federal Highway Administration, 2001).

MacMunn (United States Patent No. 4,907,360, March 13, 1990) has suggested that wrong-way entries could be reduced by posting a three-dimensional (3D) Do Not Enter sign at exit ramp terminals. This sign is depicted in Fig. 2. Unlike the standard 2D Do Not Enter sign, there is a red cone with a white stripe down the center which protrudes from the face of the 3D Do Not Enter sign. The 3D Do Not Enter sign has a clear advantage over the standard 2D Do Not Enter sign by itself (Bagchi & MacMunn, 1993). Specifically, the cone that protrudes from the face of the sign is visible to drivers who are approaching the exit ramp terminal before they make a turn. This same advantage can be obtained by mounting One-Way signs at exit ramp terminals in addition to the standard 2D Do Not Enter signs. Note that the One-Way sign is positioned perpendicular to the...
Do Not Enter sign, so it is visible to drivers before they make the wrong turn. In fact, as already noted above the current recommendations in the Manual on Uniform Traffic Control Devices (2003) include the installation of both One-Way and two-dimensional Do Not Enter signs at exit ramp terminals.

The 3D Do Not Enter sign may also have several advantages over the combined 2D Do Not Enter plus One-Way sign. First, red and white signs have been found to elicit responses more quickly than black and white signs (Hulbert & Beers, 1966). This suggests that the signs can themselves be read more quickly. If this is the case, then given that a driver is paying limited attention to the signage, the red and white cone on the 3D Do Not Enter sign may be processed more quickly and therefore seen more often than the black and white One-Way text and arrow on the combined 2D Do Not Enter and One-Way sign. As a caveat, it should be noted that the color and luminance contrast of red and white signs is less than that of black and white signs, so perhaps the speed advantage would not hold up except in bright sunlight.

The 3D Do Not Enter sign may have still another advantage over the combined 2D Do Not Enter plus One-Way sign. Note that the visual image that the red and white cone presents to the driver from the side is very similar to the image presented to the driver when facing a Do Not Enter sign head on. This image may draw attention to itself since, at least on the road, it is always mapped to the same response (do not enter). A large number of laboratory studies indicate that when a stimulus is mapped consistently to a response the processing of that stimulus can take place more or less automatically (Schneider & Shiffrin, 1977). This may hold true as well for the image presented to the driver by the red and white cone on the 3D Do Not Enter sign.

In summary, there is much to recommend the 3D Do Not Enter sign as a possible alternative to the 2D Do Not Enter and 2D Do Not Enter plus One-Way signs. Thus, we want to compare drivers' performance using these two signs. Field studies are one way to make this comparison. Studies
run in the laboratory where individuals must view the actual pictures or drawings of the various signs are another way to go. We chose instead to use a driving simulator.

2. Experiment 1

In the first experiment, an attempt was made to determine to what extent a side view of the 3D Do Not Enter sign communicates relevant warning information to drivers who have not previously been exposed to the sign. In particular, a test was made of the hypothesis that the 3D Do Not Enter sign when viewed from the side communicates the same message as the 2D Do Not Enter (and 3D Do Not Enter) when viewed head on. As noted above, the visual projection of the 3D Do Not Enter sign on the retina when viewed from the side is similar to the visual projection of the 2D Do Not Enter on the retina when viewed head on. Thus, there is reason to believe that the 3D Do Not Enter sign might well prevent more wrong-way entries than the 2D Do Not Enter sign, especially for drivers making a right turn, since it is visible from the side as well as head on. Additionally, a test was made of the hypothesis that Do Not Enter signs on the right by themselves are less likely to prevent wrong-way entries than Do Not Enter signs on the left by themselves. The Do Not Enter signs on the right are not completely visible before the driver begins the turn whereas such is not true for the Do Not Enter signs on the left (Fig. 1).

2.1. Method

Participants. Forty-eight students (36 males, 12 females), all with a current driver’s license, attending the University of Massachusetts were selected. Both undergraduate and graduate students were included. All participants were monetarily compensated for their participation.

Visual database. The visual world through which the drivers navigated was constructed using Designer’s Workbench, a three-dimensional modeling tool from Centric Software. A total of six basic scenarios were constructed, 2 control scenarios (arbitrarily labeled scenarios 1 and 2) and 4 test scenarios (arbitrarily labeled scenarios 3–6). Each scenario contained a total of nine intersections, two entrances, and two exits (see Fig. 3). The intersections are labeled #1–#9. The two entrance and exit pairs occurred between intersections #5 and #6 and intersections #7 and #8. The number of lanes varied from one (e.g., right after intersection #5), to two (e.g., between #3 and #4), to four (e.g., between #1 and #2).

Various signs were posted on the roadways at the points indicated in the plan view including airport guide, STOP, One-Way, No Left Turn, 2D Do Not Enter, 3D Do Not Enter, Bike Lane and Number signs. All signs were rendered with color and shading. The 3D Do Not Enter sign subtended the same visual angle (when facing it head on) as did the 2D Do Not Enter sign. The dimensions of the 3D Do Not Enter sign are described in Bagchi and MacMunn (1993). The Bike Lane sign is a red and white sign that looks, from a distance, not much different than the 2D Do Not Enter sign but serves merely as an indication that the break down lane is reserved for bicyclists. Such a sign was used so that participants did not automatically associate a wrong-way entry with an exit ramp terminal posted with a red and white sign (regardless of its content). The last set of signs, the Number signs, was posted as two opposing groups of three signs each on the left and right-hand sides of the road, where each sign contained a two digit number.
The number on the signs in a group increased or decreased by threes in some cases. In other cases, they did not descend or ascend in an orderly fashion. The Number signs were used to increase the load placed on drivers (Szymkowiak, Fisher, & Connery, 1997; Katsikopoulos, Duse-Anthony, Fisher, & Duffy, 2000).

In each of the four test versions of the basic scenario, there were two critical turns, one left turn and one right turn. Both turns occurred near the end of a scenario. The critical left turn was the next to last left (#7, Fig. 3) and the critical right turn was the very last turn in a scenario (Fig. 3, #100 meters).
In scenario 3 the critical left turn was posted with a 2D Do Not Enter sign on the side of the turn closest to the driver. The side of the turn farthest from the driver contained a Bike Lane sign. The subsequent critical right was posted with two Bike Lane signs, one on either side of the turn. Scenario 4 was identical to scenario 3 except for the posting of a 3D Do Not Enter sign at the critical left turn. In scenario 5, the critical right turn was posted with a 2D Do Not Enter sign on the side of the turn closest to the driver. The side of the turn farthest from the driver had a single Bike Lane sign. The critical left turn was posted with two Bike Lane signs. Scenario 6 was identical to Scenario 5 except for the posting of a 3D Do Not Enter sign at the critical right turn.

In addition, there were two control scenarios included to provide initial practice for the subjects (scenarios 1 and 2). These scenarios were identical to the experimental scenarios except that both critical turns were posted with Bike Lane signs on either side of the turn. The one difference between the two control scenarios was that only the second scenario had Number signs. Thus, the first scenario gave subjects practice at simply driving the car through a virtual world. The second scenario gave subjects practice at the secondary task, judging number order.

**Experimental design.** The 48 participants were randomly assigned to one of six groups (eight participants per group). Each participant drove a total of 4 of the 6 basic scenarios. All participants drove the two control scenarios, first control scenario 1 and then control scenario 2. After completing the two control scenarios, the participants then drove two of the four test scenarios, the exact two depending on the group to which they were assigned. The assignments of scenarios to groups are listed in Table 1. For example, the participants in Group 1 drove scenarios 1, 2, 3 (2D-L), and 6 (3D-R). (The parenthetical listing of 2D-L after scenario 3 is there simply to help the reader remember that in scenario 3 the 2D Do Not Enter sign was posted on the left; similarly the parenthetical listing of 3D-R after scenario 6 is there as an indication that the 3D Do Not Enter sign was posted on the right.) Note that for the test scenarios in each group, the participant saw the lead car make one wrong-way left-hand entry and one wrong-way right-hand entry. Moreover, for each of groups 1–4, one of these wrong-way entries involved a 2D Do Not Enter sign, the other a 3D Do Not Enter sign.

**Procedure.** The participants were asked to follow a lead car heading towards the airport. The lead car was programmed to follow a path to the airport at a velocity of 30–35 kilometers per hour. It slowed at on and off ramps and stopped at intersections activating its blinker at an appropriate distance from a turn. The lead car was programmed to make a wrong turn (a turn in a direction opposite that indicated by an airport guide sign) at intersection #4 (see Fig. 3) in each

<table>
<thead>
<tr>
<th>Group</th>
<th>Control scenarios</th>
<th>Experimental scenarios</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Scenario number</td>
<td>Scenario number</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>
scenario. Additionally, in test scenarios 3 and 4 it made one wrong-way entry at the critical left turn while in test scenarios 5 and 6 it made one wrong-way entry at the critical right turn.

In order to make sure that the participants' attention was fully engaged in the entirety of the driving task, the participants were asked to indicate to the experimenter whether the lead car took a wrong turn (e.g., the lead car turned opposite the direction specified by an airport guide sign), whether the lead car made an illegal maneuver (e.g., a U-turn where one was prohibited), or whether the Number signs on both sides of the road were or were not increasing or decreasing by threes. The participants were not told either that nonstandard signs would appear or that the lead car might make an illegal entry. Since the critical turns appeared in the last two scenarios, the driver had negotiated at least 24 intersections and 12 entrances and exits before confronting the first wrong-way entry and at least 33 intersections and 16 entrances and exits before confronting the second wrong-way entry.

**Dependent variables.** Participants' responses were measured only in the last two experimental scenarios. Specifically, whether the participant did or did not notice the lead car's illegal entry at the test ramp was recorded by the experimenter.

### 2.2. Results

Table 2 presents the number of participants in each group who missed the critical wrong-way entry in both experimental scenarios. Two results stand out. First, by summing the number of misses over all six groups within sign presentation side (left or right) it is clear that the number of wrong-way entries on the left missed by drivers (7 or 15%) is much smaller than the number of wrong-way entries on the right missed by drivers (24 or 50%). The difference between proportions is statistically significant, \( \chi^2(1) = 13.77, p < 0.001 \). More to the point, consider just the first time wrong-way entries (i.e., consider just the first test scenario). In this case the proportion of wrong-way entries on the left missed by drivers (3 or 9%) is now even smaller than the proportion of wrong-way entries on the right missed by drivers (11 or 69%). Again this difference was highly significant, \( \chi^2(1) = 24.58, p < 0.001 \). Second, averaging the results over both sides of the road, one finds that the drivers were slightly more likely to miss a 3D Do Not Enter sign (33%) than they were to miss a 2D Do Not Enter sign (31%). However, this difference is not statistically significant. Moreover, the number of drivers missing the 3D Do Not Enter sign did not differ from the number of drivers missing the 2D Do Not Enter sign when the analyses were confined to just the signs on the left, just the signs on the right, or just the signs at the first critical turn.

<table>
<thead>
<tr>
<th>Group</th>
<th>Scenario name (first critical turn)</th>
<th>Number missed</th>
<th>Scenario name (second critical turn)</th>
<th>Number missed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(2D-L)</td>
<td>1</td>
<td>(3D-R)</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>(3D-L)</td>
<td>0</td>
<td>(2D-R)</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>(2D-R)</td>
<td>5</td>
<td>(3D-L)</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>(3D-R)</td>
<td>6</td>
<td>(2D-L)</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>(2D-L)</td>
<td>1</td>
<td>(2D-R)</td>
<td>4</td>
</tr>
<tr>
<td>6</td>
<td>(3D-L)</td>
<td>1</td>
<td>(3D-R)</td>
<td>3</td>
</tr>
</tbody>
</table>
2.3. Discussion

The cone on the 3D Do Not Enter sign is obviously visible to drivers as they approach an exit ramp. Yet, the drivers were no less likely to miss a 3D Do Not Enter sign than they were to miss a 2D Do Not Enter sign. Not only was this result true overall, but it was true for restricted roads on both the left and right-hand side and it was true when just the first test scenario wrong-way entries were analyzed. Clearly, the 3D Do Not Enter sign does not provide any added benefit for naive drivers (drivers who have never seen the sign previously). However, it may well do so for drivers who know what it means. And, normally this would be the case since, presumably, some rudimentary attempt would be made to increase the public’s awareness of the new sign if and when it were to be introduced.

3. Experiment 2

In the second experiment, an attempt was made to determine whether drivers who had been exposed to the 3D Do Not Enter sign before the experiment began would be less likely to make a wrong-way entry when seeing a 3D Do Not Enter sign than when seeing a 2D Do Not Enter sign, either by itself or together with a One-Way sign. It is predicted that the 3D Do Not Enter sign will function better than the 2D Do Not Enter sign by itself. It is not clear whether it will function at least as well as the combined 2D Do Not Enter and One-Way sign. The 3D Do Not Enter sign communicates the wrong-way entry information from the side using only symbology; the 2D Do Not Enter plus One-Way sign uses both symbology (the arrow) and text (One-Way).

3.1. Method

Participants. A total of 60 participants (30 males and 30 females), all students at the University of Massachusetts with a current driver’s license, were run in the second experiment. All participants were paid for their time.

Visual database. A total of one control and three test scenarios were constructed from the basic scenarios used in Experiment 1. There was only one critical turn, the last right-hand turn. In the control scenario the critical turn was signed by two Bike Lane signs. In the remaining three test scenarios, the last critical right-hand turn was signed either by a 2D Do Not Enter, 2D Do Not Enter plus One-Way or 3D Do Not Enter sign on one side of the turn and a Bike Lane sign on the other. The One-Way sign was mounted on a 2D Do Not Enter sign perpendicular to the face of the latter sign (Fig. 4). Otherwise, the stimuli were identical to those used in Experiment 1.

Experimental design. Twenty drivers were assigned to each of three experimental conditions: 3D Do Not Enter, 2D Do Not Enter, and combined 2D Do Not Enter plus One-Way. All drivers navigated the control scenario and then one (and only one) of the experimental scenarios.

Procedure. In Experiment 2, all 60 drivers were exposed to six different views of the 3D Do Not Enter sign during each of three short practice runs. Specifically, signs that would appear during the actual experiment (regulatory, warning and guide signs) were displayed on both the left and right-hand sides of a long, straight stretch of road. Participants had to read the text on the sign as they passed it by. They drove very slowly and plenty of space was allowed between signs.
Among the signs, the 3D Do Not Enter sign appeared once on the left and once on the right. During the first practice run, signs which normally did not face approaching traffic (e.g., the various Do Not Enter signs) were rotated so that they did face the driver. In the second practice run, the signs that had been rotated 90° were now rotated only 60°. And finally, in the third practice run, all signs were posted as normally they would be. As a result, subjects were exposed to six different views of the 3D Do Not Enter sign before beginning to drive through the test scenarios.

The remaining procedure was identical to the one used in Experiment 1, including the use of Number signs. A driver had to follow a lead car. In the first scenario, the lead car made wrong (not illegal) turns. Number signs were included as well. In the second scenario, the lead car made wrong turns and one wrong-way entry at the critical turn. Thus, the driver had negotiated a total of 17 intersections and 8 entrances and exits before confronting the wrong-way entry.

3.2. Results

The participants missed the 3D Do Not Enter sign less often (25% or 5 out of 20 drivers) than they missed the 2D Do Not Enter sign (35% or 7 out of 20 drivers), but the difference in proportions was not significant. The best performing sign was the combined 2D Do Not Enter plus One-Way sign. Only one (5% or 1 out of 20) of the drivers missed this sign. The proportion of drivers missing this sign was significantly less than the proportion missing either the 2D Do Not Enter ($\chi^2(1) = 5.63, p < 0.025$) or the 3D Do Not Enter ($\chi^2(1) = 3.14, p < 0.07$) signs.

3.3. Discussion

The fact that the 3D Do Not Enter sign did not perform as well as the 2D Do Not Enter plus One-Way sign may indicate that the practice sessions did not really accomplish what was intended.

Fig. 4. 2D Do Not Enter plus One-Way signs are mounted perpendicular to each other.
and, instead, drivers forgot what message was conveyed by the red and white protruding cone on the 3D Do Not Enter sign by the time they encountered it in the experimental scenario. One way to check this is to determine whether exposed drivers are more likely to notice wrong-way entries than naive drivers. In fact, this is clearly the case. Specifically, fully 75% of the participants in Experiment 1 missed the wrong-way entry when it was signed by a 3D Do Not Enter sign on the right-hand side and it was the first wrong-way entry to which they were exposed. However, only 25% of the participants in Experiment 2 missed the 3D Do Not Enter sign on the right-hand side (by design it was always the first and only wrong-way entry to which they were exposed). Thus, previous exposure resulted in an improvement in performance for the 3D Do Not Enter sign.

There are good reasons to pursue further modifications to the 3D Do Not Enter sign given that it does appear to become considerably more effective when drivers have been exposed to it. Primary among these reasons is that when installed the 3D Do Not Enter sign always presents a side view to the approaching driver. Thus, there are never the problems that come when only the 2D Do Not Enter sign is mounted by itself (as is often, unfortunately, the case). There are also good reasons to pursue further modifications to the 2D Do Not Enter plus One-Way sign, modifications that are rooted in theory. Both modifications are discussed in Experiment 3 below.

4. Experiment 3

In Experiment 3, an evaluation is made of modifications to the 3D Do Not Enter and 2D Do Not Enter plus One-Way signs. To begin, consider modifications to the 3D Do Not Enter signs. Although the 3D Do Not Enter sign did not perform as well as the 2D Do Not Enter plus One-Way sign, the above evidence from Experiment 2 suggests that the 3D Do Not Enter sign could be improved much as the 2D Do Not Enter sign is improved by the addition of a One-Way sign to it. So, it was decided to embed a One-Way sign in the 3D One-Way sign in the middle of the white bar facing the driver from the side (Fig. 5b). Additionally, it was decided to test the effect of adding just chevrons to the 3D Do Not Enter sign (Fig. 5a). The One-Way sign when embedded in the white shaft of the 3D Do Not Enter sign may be difficult to see because of the constraints on its size. By contrast, the chevrons were clearly visible.

Next, consider modifications to the 2D Do Not Enter plus One-Way sign. At first glance, it might appear that there is no really compelling reason to make modifications to this combined sign. After all only 5% of the drivers failed to notice the wrong-way entry (on the other hand, any percentage, no matter how small, is clearly unacceptable). Still, there is evidence to suggest the One-Way portion of the combined sign may place too high a load on drivers' spatial resources and require one too many steps to reach a decision. Specifically, it has long been acknowledged that there are multiple pools of central resources, one pool associated with spatial reasoning and another pool associated with verbal reasoning (Wickens, Sandry, & Vidulich, 1983). Now it is arguably the case that in order to understand the One-Way sign, drivers need to draw most heavily upon the spatial pool of resources. Specifically, the arrow specifies the direction and the text specifies that travel is restricted to the direction indicated by the arrow. A driver then must infer that travel in the opposite direction is prohibited (the opposite direction being determined, in essence, by rotating the arrow spatially 180° around the depth axis) and conclude, therefore, that a
right-hand turn is prohibited. Not only does this inference draw upon the spatial pool of resources (which are already taxed by the driving task during), but it adds to the time it takes the driver to reach a decision (e.g., Clark & Chase, 1972).

The above line of argument suggests that a sign which avoided most (if not all) spatial reasoning would be preferable to any of the existing signs. That is, the driver might be better able to process the information in the sign at the exit ramp terminal if he or she could do such with the verbal resources that are going untapped. One way to draw upon these resources would be
to present a sign facing the driver that said No Right Turn (without any symbology) along with
the usual One-Way sign above it (Fig. 5c). The message, No Right Turn without the usual symb-
ology, can be processed verbally in its entirety and so does not draw directly on limited spatial
resources.

4.1. Method

Participants. One hundred participants (68 males, 32 females), all students at the University of
Massachusetts and all having valid driver’s licenses, were run in Experiment 3. Subjects were ran-
domly assigned to one of five experimental conditions. All participants were monetarily compen-
sated for their participation.

Visual display. A total of one control and five test scenarios were constructed from the basic
scenario used in Experiment 1. Five different wrong-way entry signs were used, one in each test
scenario: 2D Do Not Enter, 2D Do Not Enter plus One-Way, 3D Do Not Enter with chevrons
embedded in the white band circling the cone (Fig. 5a), 3D Do Not Enter with a One-Way sign
embedded in the cone (Fig. 5b), and combined One-Way plus No Right Turn sign (Fig. 5c).
Although obvious from the figure, it should be noted that the One-Way sign was actually embed-
ded on the side of the 3D Do Not Enter sign (and it is why we refer to this condition as the 3D Do
Not Enter with embedded One-Way rather than 3D Do Not Enter plus One-Way). Additionally,
it should be emphasized that the No Right Turn sign did not have the usual graphics (i.e., a right
angle with a slash through it).

Experimental design. Twenty subjects were randomly assigned to each of the 5 different wrong-
way entry signs being evaluated.

Experimental procedure. The participants were exposed to the following signs in three short
practice runs: 3D Do Not Enter with embedded chevrons, 3D Do Not Enter with embedded
One-Way, 2D Do Not Enter plus One-Way, One-Way plus No Right Turn, and One-Way plus
No Left Turn. The last sign was used because participants were asked to read signs on both
the left and right-hand sides of the road during the practice runs. The signs were rotated just
as they were in Experiment 2 during each of the first, second and third practice runs. After the
practice runs, each participant drove the control scenario and then was tested on one of the five
experimental scenarios. Each of the five test scenarios was identical except for the critical wrong-
way sign that appeared at the last right-hand turn. As in the earlier experiments, Number signs
were included at four driver decision points within the test scenario (Fig. 3).

There were two new additions to the procedure in each experimental scenario. Because there
was only one miss for the 2D Do Not Enter plus One-Way sign, there was little possibility that
we could observe a significant improvement in performance with the addition of a No Right Turn
sign. Thus, we made two changes in the procedure in an attempt to increase the miss rate for the
2D Do Not Enter plus One-Way sign. First, at intersection #6 (a right turn; see Fig. 3), we gave
drivers a preliminary exposure to their test sign, specifically the version of the test sign that pro-
hibited a left turn. At this turn, the lead car made a legal right turn, and the participant was ex-
pected to make no response to this sign. Thus, we exposed subjects to the test sign during the
driving task in a situation in which no illegal turn was made. This meant that at the test intersec-
tion (#9), subjects already had a legal turn associated with the test sign. Second, we decided to
increase the load on the driver. Specifically, at four points in each scenario we asked participants
to identify the color of a word which itself was the name of a color. At the last critical turn, the word name (e.g., red) was different from the color in which the name was written (e.g., blue).

4.2. Results

The results of the third experiment are presented in Table 3. No subjects missed the One-Way plus No Right Turn sign. Two subjects missed the 2D Do Not Enter plus One-Way sign. Participants performed significantly better on the One-Way plus No Right Turn sign than they did on the 3D Do Not Enter sign with embedded chevrons ($\chi^2(1) = 4.44, p < 0.05$), the 3D Do Not Enter sign with an embedded One-Way ($\chi^2(1) = 7.06, p < 0.01$), and the 2D Do Not Enter sign by itself ($\chi^2(1) = 7.06, p < 0.01$). Although performance was numerically better for One-Way plus No Right Turn compared with the 2D Do Not Enter plus One-Way (0 vs. 10% misses respectively), the difference was not significant. This may reflect a ceiling effect. A comparison of the misses for the 2D Do Not Enter sign and the 2D Do Not Enter sign plus One-Way signs in this experiment with Experiment 2 suggests that the changes in procedures in Experiment 3 that were intended to increase the miss rate did not do so appreciably. Finally, although participants performed better on the 2D Do Not Enter plus One-Way sign than the 2D Do Not Enter sign by itself, the 3D Do Not Enter with embedded One-Way, or the 3D Do Not Enter with embedded chevrons, these differences were not statistically significant.

4.3. Discussion

The finding that no participants made a wrong-way entry when presented the One-Way plus No Right Turn sign is consistent with the hypothesis that the less inferencing required, and in particular the less spatial inferencing required, the more likely a driver is to notice a wrong-way entry. However, further evaluation is clearly required since it was not possible to differentiate statistically between the performance of drivers seeing the aforementioned sign and the performance of drivers seeing the 2D Do Not Enter plus One-Way sign. This evaluation would be enhanced were the position of driver’s eye movements monitored. In this case, if drivers fixated equally often on both types of signs, but made fewer wrong-way entries with the One-Way plus No Right Turn sign, one could then discount possible differences in conspicuity.

We should note that the finding of no wrong-way entries in the One-Way plus No Right Turn condition may be a consequence, not of the decrease in spatial inferencing required of drivers, but instead of the inclusion of two relevant directional signs as drivers approach the exit ramp.

<table>
<thead>
<tr>
<th>Sign</th>
<th>Number</th>
<th>Percent (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2D Do Not Enter</td>
<td>6</td>
<td>30</td>
</tr>
<tr>
<td>2D + One-Way</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>3D with chevrons</td>
<td>4</td>
<td>20</td>
</tr>
<tr>
<td>3D with One-Way</td>
<td>6</td>
<td>30</td>
</tr>
<tr>
<td>One-Way + No Right Turn</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
terminal. Thus, drivers given two One-Way signs may have performed just as well as drivers given a One-Way sign plus a No Right Turn sign. However, based on prior research (Clark & Chase, 1972; Wickens et al., 1989), we believe that the reduction in the number of wrong-way entries would not be as great with the redundant One-Way signs because both require a spatial inference not required by the No Right Turn sign and because both tap into spatial resources which are heavily in demand during driving, whereas the No Right Turn sign draws mostly on verbal resources which are in considerably less demand.

We should also comment on the finding that the 3D Do Not Enter sign with an embedded One-Way sign performed significantly worse than the 2D Do Not Enter plus One-Way sign. We had expected performance with these two signs to be about the same. The difference is probably attributable to the fact that the embedded One-Way text subtends a smaller visual angle than the One-Way text when it is presented by itself, as must be the case if the One-Way sign is going to be included in the white band circling the cone of the 3D Do Not Enter sign. Thus, the embedded One-Way sign may not have been visible until the last couple of seconds before the turn. This would also be true for the embedded chevrons. If drivers were distracted during the turn, then the most important information would come long before the turn. The high visibility of the One-Way sign by itself would be at an advantage here.

5. General discussion

At least four of the more obvious limitations of this study need to be mentioned before summarizing the above three experiments. First, the various signs were all evaluated during brightly lit, daytime conditions. No conclusions should be drawn about the effectiveness of the different types of Do Not Enter signs during the nighttime. When the conspicuity of a sign is much greater than anything else in the immediate vicinity, as might be the case for the 3D Do Not Enter sign at night, it may be sufficient to attract and hold the attention of the drivers. Clearly this requires testing.

Second, given the years of experience our subjects had with the standard 2D Do Not Enter signs, they were relatively inexperienced viewers of the 3D Do Not Enter signs even with the prior exposure we gave them in Experiments 2 and 3. It may well be that with much more experience, performance on the 3D Do Not Enter signs would eventually be comparable to that of the most effective 2D Do Not Enter signs.

Third, these experiments were run using a driving simulator rather than on the open road. Thus, the results may or may not generalize to the open road. However, it should be noted in this regard that in Experiment 2 the number of misses for the 2D Do Not Enter plus One-Way sign was significantly lower than for the 2D Do Not Enter alone. This finding is consistent with existing crash statistics.

Fourth, although poorly understood signs do cause problems for drivers (Smith, 1976), not all crashes can easily be prevented by better signs. It has been argued that some wrong-way crashes are caused by One-Way signs which are poorly located (Rinde, 1978). Other wrong-way crashes are due to driver error. For example, many, though not all (Vaswani, 1974), of the wrong-way fatal accidents occur at night and involve drivers with blood alcohol levels exceeding 0.20 percent (Case & Hulbert, 1975). These accidents suggest the need for devices which physically signal the
wrong-way entry such as raised pavement markers (Shepard, 1976) or vehicle-actuated audio or visual warnings (Friebele, Messer, & Dudek, 1971). Additionally, some wrong-way crashes occur simply because drivers fail to pay attention (Shinar, 1978), a failure which is particular likely in older drivers (Madden, 1986).

6. Summary

Wrong-way entries can end tragically. Changes in the signage could potentially reduce the number of such entries. As such, alternatives to the currently recommended 2D Do Not Enter plus One-Way sign were evaluated, including both 3D Do Not Enter signs and modifications to 2D Do Not Enter signs. One somewhat surprising conclusion from these studies is that displaying to drivers a sign containing a standard shape and color scheme (white bar in red surround, i.e., the 3D Do Not Enter sign) clearly located where one would find a traffic control device, even when drivers are experienced with the sign, is less effective than displaying the more standard 2D Do Not Enter plus One-Way sign. A second finding is suggestive, but requires further evaluation. In particular, adding a No Right Turn sign to the 2D Do Not Enter plus One-Way sign decreased the absolute number of wrong-way entries. Whether such a decrease would be statistically significant still needs to be determined. Interestingly, were the No Right Turn sign to prove effective, then its benefits would be realizable only in countries like the United States where text is still heavily used in such signs. In the Europe where symbolic signs are used almost exclusively, one would not expect to be able to find a sign with an advantage similar to the No Right Turn sign.

Acknowledgments

Portions of this research were funded by grants from the Massachusetts Highway Department, the National Science Foundation Curriculum Research and Curriculum Development Program, and the National Science Foundation Engineering Infrastructure Program (SBR-9413733) to Donald L. Fisher. Tragically, the fourth author, Susan Alice Duffy, was diagnosed with bone cancer in May of 2000 and succumbed in February of 2002. Although we may have been slow redrafting the manuscript, we never wavered in our commitment to her to complete the research that she so beautifully helped guide.

References


Friebele, J. D., Messer, C. J., & Dudek, C. L. (1971). *State-of-the-art of wrong-way driving on freeways and expressways* (Research Report 139-7; Project No. 139.) College Station, TX: Texas Transportation Institute.


