Prevention of wrong way accidents on highways: a human factors approach

Perrine Ruer, Philippe Cabon, Fabrice Vienne

Prevention of wrong way accidents on highways: a human factors approach

Perrine Ruer[a], Philippe Cabon[a*], Fabrice Vienne[b]

[a]*DEDALE, Paris, France*
[b]*LEPSIS, IFSTTAR, Marne La Vallée, France*

Abstract

Every year, on highways, drivers taking wrong way cause accidents. Elderly drivers and young drivers are the most prevalent in the wrong way accidents. Two main explanations of these accidents can be identified: violation (the driver takes intentionally the wrong way) or error (the driver did not identified that he/she is taking a wrong way). This paper focuses on a Human Factors evaluation of two new road signs to prevent wrong way driving. The devices are a light barrier and the standard wrong way signal (B1) on a yellow background (B1Y). This research, carried out in a simulator, aims at evaluating the efficiency of these road signs to prevent errors and violation on elderly and young drivers. The results of tests give a qualitative and quantitative evaluation of the wrong way road signs and are discussed regarding their implication for road sign design and human factors evaluation.

Keywords: wrong-way ; Human Factors ; road signs evaluation ; risk perception ; simulation.

Résumé

Chaque année sur les routes à chaussées séparées des conducteurs s'engageant en contresens provoque des accidents. Les conducteurs âgés et jeunes sont les plus impliqués dans cette accidentologie. Deux explications essentielles ont pu être identifiées : la violation (le conducteur prend intentionnellement le contre sens) ou l'erreur (le conducteur n'identifie pas qu'il prend le contre sens). Cet article traite de l'évaluation Facteurs Humains de deux dispositifs. Les dispositifs sont une barrière de plots lumineux et le panneau sens interdit classique (B1) sur fond jaune (B1J). Cette recherche, menée en simulateur, a pour objectif d'évaluer l'efficacité de ces dispositifs pour prévenir les violations et les erreurs sur des conducteurs âgés et jeunes. Les résultats des tests donnent une évaluation qualitative et quantitative des signalisations anti-contresens et sont discutés au regard de leurs implications pour la conception de signalisation routière et leur évaluation facteurs humains.

Mots-clé: contresens ; Facteurs Humains ; évaluation de signalisations ; perception du danger ; simulation.

* Corresponding author: Philippe Cabon. Tel.: +33158393095. *E-mail address*: pcabon@dedale.net.

1. Introduction

Every year, on highways, drivers taking wrong way cause accidents. In France these accidents are known to be rare (1% of road accidents) but serious (4% of fatal accidents) (SETRA, 2008). As the general public considers that these accidents could be avoided, they have a low public acceptability and are therefore generally highly publicized.

Accidents due to wrong way are difficult to study in road safety. The wrong way entry on the road cannot be always located. When a vehicle is in wrong way, he was spotted on the road but it is difficult to know what was the entry or exit he had taken. The phenomenon is complex to explain and reduces the possibility to use a focused approach because there is a wide diversity of origins, like u-turn on a rest stop, turn around before a toll, etc. It seems necessary to develop effective prevention systems to alert the driver and to avoid taking wrong way. Several studies and reports tried to understand the problem and solve it by suggesting countermeasures. Among them, cameras at the highway exits, warning messages on the radio or yellow or red lights warnings are among the most cited (Scaramuzza and Cavegn, 2007; Moler, 2002).

In order to get a better understanding of these accidents and to evaluate possible ways of prevention, the French ministry of Transport is funding a research project named LUCOS. This project covers 3 work packages that address 3 complementary aspects of the wrong way prevention:

- A Technical work package (Centre d'Etudes Techniques de l'Equipement de l'Ouest)
- An Economics work package (Institut Français des Sciences et Technologies des Transports, de l'Aménagement et des Réseaux)
- A Human Factors work package (Dédale SAS)

1.1. Research topic

This paper reports the results from the Human Factors work package. The aim is to assess the impact of new road signs on the prevention of wrong ways. Currently, the design or selection process of road signs does not take into account any systematic human factors criteria. Therefore, a more general objective of the research is to set-up a human factors methodology for the evaluation of road signs including ergonomics criteria. The method has covered four steps: a literature review on wrong-ways accidents; an ergonomic inspection of the road sign; a static test of the road signs by the means of pictures presented on a computer and a dynamic test in a driving simulator. The 3 first steps enable to identify risk factors and provide relevant criteria to be included into the evaluation process. This paper will mainly present the results of the step, i.e. the evaluation in the driving simulator.

1.2. Risk factors

From the literature review, it was possible to identify the main risk factors associated with accidents due to wrong ways as well as the various methods of prevention in France and abroad. There is only a few statistical data in the literature as investigations are only carried out in case of serious accidents (death or injury). The risk factors identified are those related to profiles and those related to the context (the time of day, environment, etc.). The main risk factor is related to driver age (Moler, 2002). Elderly and young drivers are the most involved in wrong way accidents. Old drivers would be more involved because of the decreased cognitive abilities (Van Eslande, 2003) whereas young drivers would be more involved because of a more risk-taking behaviour. The influence of drugs or alcohol is an additional factor taking wrong way (approximately between 50% and 75%) (Cooner et al, 2004).

Therefore, two underlying mechanisms have to be distinguished in the root causes of these accidents, leading to two prevention areas:

- Driving errors due to a misperception or misunderstanding of the road signs. Error is defined as an involuntary deviation from a rule or a norm. Planned actions fail to achieve the desired outcome (Reason et al., 1990). These errors would be more prevalent in elderly drivers or impaired drivers because of a decreased ability to perceive or quickly interpret the information conveyed by the road sign. In this case, road sign design should allow enhancing perceptual aspects.

- Violation due to risk taking. Contrary to errors, violation is defined as a voluntary transgression of a rule. This voluntary action is sometime undertaken to increase productivity or even safety. In other cases, violations are observed because of a low risk perception (Reason et al., 1990). Therefore, it can be assumed that some drivers may take wrong-ways because they do not perceived a significant hazard. A way to reduce these violations will be to increase the risk perception induced by the road signs

In order to assess the ability of the road signs to decrease errors and violation, a total of 7 criteria have been identified:

- Visibility
- Intuitivity
- Incitation
- Low attention demand
- Understanding
- Risk perception
- Interdiction

The first five criteria are more related to errors whereas the two last are more associated with violation.

1.3. Evaluated road signs

The evaluated devices are a light barrier (figure 1) and the standard one-wrong way signal (B1) on a yellow background (B1Y) (fig. 2). These devices are already installed on a French highway and are also evaluated from the technical and economics perspective (see related papers in this conference).

Figure 1 - Light barrier

Figure 2 - Wrong way signal on a yellow background (B1Y)

1.4. Objectives

This research aims at evaluating the efficiency of these road signs to prevent errors and violations on elderly and young drivers.

2. Method and equipment

As wrong way situations are obviously impossible to reproduce in actual road conditions, the driving simulator was selected as this enables to evaluate the perception and the interpretation of road signs in a controlled but "ecological" situation.

2.1. Scenarios

In order to induce wrong ways situations based on errors and violation, each driver was required to drive in 2 different scenarios:

- Violation scenario: drivers were requested to follow a vehicle as close as possible to get to a destination for a very important appointment. In the instructions to the drivers, they were told that if they were not able to follow the car, they would miss their appointment. They were also told that, in the same time, they must comply with the road regulations. To create a wrong way situation, the vehicle in front turns quickly in a wrong way direction and is passing the one-way signal. This situation is expected to favor violation because of the pressure created by the instruction.

- Error scenario: the driver was asked to drive on a rest area to refuel the car and then to find the exit to the highway. In this situation, the misunderstanding is induced by the complexity of the road and creates confusion because the first road presented to the drivers is in wrong way and the right road is located few meters further. This second scenario is expected to favour errors.

2.2. Research design

The two scenarios are counterbalanced with four conditions to avoid a learning effect. The conditions are:

1) A control condition with the classic signals (B1: one-way signal)
2) Yellow background signal (B1 Y)
3) Light barrier alone.
4) Combination of new one-way signals (B1Y) with light barrier

These four road signs conditions were tested against two driver age conditions: young drivers versus elderly drivers. Each driver was driving in the control condition and was then randomly allocated to one of the 3 new road signs conditions. Therefore, each driver was running 2 scenarios, one in the control condition, the other with the new road sign.

Four hypotheses were tested in this research:
- Elderly drivers do more wrong way than young drivers.
- Elderly do more wrong way by error than young drivers. But young drivers do more wrong way by violations than elderly.
- New road sign (B1Y, light barrier and combination) reduce the wrong way due to errors from the current signal (B1).
- The new signals increase the risk perception and allow young driver to detect the wrong way better than the existing road sign.

2.3. Sample of drivers

Two drivers population were evaluated: young drivers aged between 20 and 30 years old and elderly drivers having more than 70 years old. In an experiment on driving simulator, a loss of 20 % of participants can be expected because of the simulator sickness. Three criteria were required to be included in the research: 1) have the driving license, 2) have a normal or corrected vision, 3) be aged between 20 and 30 years old or have more than 70 years old. To check these criteria, the selection was made by the means of a questionnaire by phone or email. 30 young and 34 elderly were recruited for the dynamic tests. Table 1 describes the two groups of drivers.

Table 1 - Driver sample description

	Young	Elderly
N	30 (16 males, 14 females)	34 (15 males, 19 females)
Mean age	25	75
Mean driving experience (in km/year)	7571	5674

2.4. Data collection

The data collected is covering both a qualitative approach on user behaviour (verbalization while driving and interview) and quantitative approach with the number of wrong way and the questionnaires.

The data collection took place over a period of 14 days. Each driver was requested to sign an informed consent before the experiment. A gift voucher of fifty euros compensated the subject's participation.

Each session was lasting around 1 hour. Upon arrival, the driver was requested to fill two questionnaires: the first questionnaire on their driving habit (frequency of driving, driving experience on different roads) and the *Simulator Sickness Questionnaire* (Kennedy et al, 1993) on physical or mental disturbances caused by the simulator. The second questionnaire, the *Driver Behaviour Questionnaire*, evaluates risky behaviours (Reason et al, 1990).

Then, the subject performs a training phase of the simulator during 10 minutes. After the experimenter read the instructions aloud, the session was starting.

At the end of the experimentation, each driver was asked to evaluate several criteria for every road signs presented on a PowerPoint support. Before leaving, the subject answers again the *Simulator Sickness Questionnaire* to ensure that she/he has not physical and / or mental discomfort. The subjects are only informed after the experimentation of the research objectives to avoid any influence on their behaviour.

2.5. Simulator

The study was conducted on a small-scale interactive driving simulator, comprising control devices (force-feed-back steering wheel, gear lever, gas and brake pedals) as well as visual and auditive rendition devices. The visual scene and the scenarios were generated by an in-house software developed at IFSTTAR. The images generation included HDR (High Dynamic Range) rendering. It creates more realistic scene. The road environment was displayed on 3 screens: covers 150 ° field of vision of the driver (fig.3).

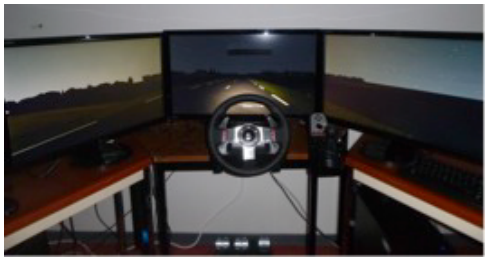

Figure 3 - Simulator

3. Results

Among the 64 drivers 6 elderly drivers were excluded: two did not continue the test after the training phase, three others stopped during the scenarios because of simulator sickness and one driver did not meet the age criteria. The data have been collected on a sample of 58 subjects. 30 subjects aged between 20 and 30 years (mean = 25, min = 20, max = 30) and 28 subjects over 70 years (mean = 75, min = 70, max = 82).

3.1. Effects of age and road signs on number of wrong ways

Figure 4 compares the number of wrong ways in both scenarios for young and elderly drivers for all road signs conditions. This shows that young drivers took more wrong ways compared to elderly drivers. However, there is a significant difference only for the scenario 1 (violation). Therefore this result confirms the hypothesis that young drivers would take more wrong ways because of an increased risk taking behaviour. A non-significant trend is observed in the scenario 2 suggesting that elderly drivers would take more wrong ways by error.

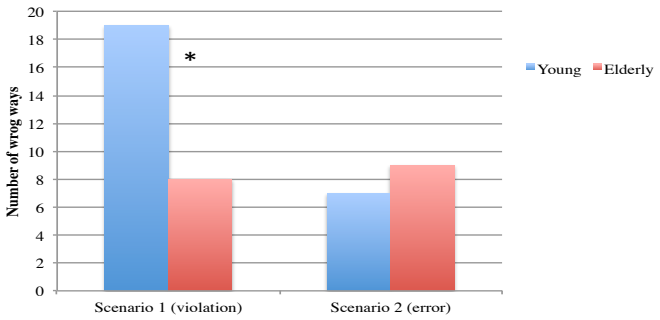

Figure 4 – Comparison of the total number of wrong ways for young and elderly drivers in scenario 1 and 2

Table 2 shows the number and percentage of drivers taking a wrong way in the different road sign conditions and scenarios. The first interesting result is that the traditional road sign induced frequent wrong ways, up to 23% for young drivers in the violation scenario. The road sign “light” was the least efficient as it produced from 30 to 50% of wrong ways. It shows that the light barrier by itself is not efficient to prevent wrong ways. When

compared to the condition B1Y, no difference in the number of wrong ways is observed, suggesting that the yellow background has the greatest effect.

Table 2 – Number and % of drivers taking a wrong way according to age, scenarios and road signs.

	Scenario 1 (violation)		Scenario 2 (error)	
	Young (n=30)	Elderly (n=28)	Young (n=30)	Elderly (n=28)
B1 (control condition)	7 (23%)	3 (11%)	2 (7%)	4 (14%)
B1Y	0 (0%)	1 (10%)	0 (0%)	1 (10%)
Light	5 (50%)	3 (30%)	5 (50%)	4 (40%)
B1Y+Light	2 (20%)	0 (0%)	1 (10%)	0 (0%)

NB: all the drivers were included in the B1 condition and in one of the 3 new road condition.

Therefore, the hypothesis that new road signs would reduce the wrong ways compared to the existing signal (B1) is confirmed except for the light condition.

3.2. Effects of driver age on road signs perceptions

As already mentioned a "good" road sign should be easily perceived and understood to prevent errors and should convey a sufficient level of interdiction and risk perception to prevent violations. The Table 3 compares the results of risk perception and interdiction of each road sign for young and elderly drivers. At the exception of the "light" which was rated at very low levels, all the other road signs were perceived at a high level of risk and interdiction. However, it is worth noting that these levels vary with the driver age. For young drivers, the combination (B1Y+light) is associated with the highest level of interdiction and risk. The elderly drivers rated the highest levels to the traditional road sign. This could be explained by the fact that elderly drivers have been extensively exposed to the traditional road sign. These results are consistent with the number of wrong ways that were suppressed in the violation scenario by the B1Y for young drivers (see table 2). However, the elderly drivers rated a moderate risk perception for B1Y.

Table 3 - Subjective rating (mean ± standard deviation) of risk perception and interdiction

Risk perception		
	Young	Elderly
B1	4,5±0,6	4,9±0.3
B1Y	4,3±1	3,6±1.2
Light	1,4±1.1	3,4±1.7
B1Y +Light	4,9±0.3	4,8±0.5
Interdiction perception		
	Young	Elderly
B1	4,7±0.7	4,9±0.4
B1Y	4,6±0.7	4,4±0.9
Light	1,1±1	3,6±1.7
B1Y +Light	4,9±0.3	4,6±0.5

The interview (at the end of the simulation) allows qualitative results, i.e. a road signs perception through the 7 criteria (visibility, intuitivity, incitation, low attention demand, understanding, risk perception and interdiction). A summary of results is provided in the Table 4.

Table 4 - Positive and negative points for each road sign

	Positive points	Negative points
Existing B1	Good visibility Draw attention Immediate understanding High incentive to stop Very good perception of risk and interdiction	
B1 Yellow background	Good visibility Draw attention Understanding of the existing signal B1 High incentive to stop Good perception of risk	Incomprehension of the yellow colour
Light barrier	Visible Draw attention due to the flashing light and the red colour	Misunderstanding of the meaning Low incentive to stop No barrier effect Perception of risk very low
Combination	Good visibility Draw attention (In first B1Y and in second, barrier light) Immediate understanding High incentive to stop Very good perception of risk	Misunderstanding of the barrier

These results show that most of the road signs are well perceived and understood by the drivers, except the light barrier alone. However, when added to a B1Y, light provides a high level of risk perception. Although the B1Y led to a reduction of wrong way, the yellow colour was not easily interpreted. Some drivers perceived this colour as an indication of a temporary signalization.

It is also worth noting that the subjective perception of these road signs is not totally consistent with the quantitative analysis. In fact, even if the yellow colour or the light are not well understood by the drivers, they are the most efficient to reduce the number of wrong ways. This suggests an automatic processing of the road sign by the drivers. As it could be expected, none negative points were raised by drivers as they are used to see this road sign on current roads.

4. Conclusion

This paper reports a Human Factors evaluation of new road signs that are intended to prevent wrong-ways. The simulators sessions were played with two scenarios on 58 young and elderly drivers. The results show that young drivers took more wrong ways than elderly and that most of these wrong ways were due to violations. The new road signs were more efficient to prevent the wrong ways compared to the existing road sign. Even if they were efficient to prevent wrong ways, the yellow background is not always understood. The light barrier by itself led to misunderstanding and does not indicate the hazard. Therefore, even if the results of this evaluation suggest that these new road signs reduced objectively the number of wrong ways, it should be noticed that the subjective evaluation of the road signs is less clear.

Even if the results obtained enable to answer to the questions, the method used in this Human validity of the tests on the simulator is a point of discussion. In addition to the well-known simulator sickness that affected several subjects who were excluded from the experiment, the simulator had some limitations especially regarding the high sensitivity of the steering wheel and pedals. The latters did not allow the replicate of real feelings. This may

have biased the experiment especially for elderly. Indeed, several subjects paid more attention on handling the car. In a few cases, it may have an impact on the detection of the road signs.

This methodology could be extended and generalized by the means of the application of ergonomic criteria at various steps of the design process of the road signs as it is done for the evaluation of the Man-Machine Interface. This human factors approach would allow identifying as early as possible issues related to road sign perception and understanding and therefore would enable to correct these issues before their implementation on the field.

Acknowledgements

This work is funded by the Direction de la recherche et de l'Innovation (DRI) from the Ministère de l'Ecologie, de l'énergie, du développement durable et de la mer, Commissariat général au développement durable.

References

Cooner, S-A. Scott, A., Ranft, E. (2004). Contermeasures for wrong way movement on freeways: Overview of project activities and findings. http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/4128-1.pdf

Kennedy, R.S., Lane, N.E., Berbaum, K.S., Lilienthal, M.G. (1993). Simulator Sickness Questionnaire: An enhanced method for quantifying simulator sickness. International Journal of Aviation Psychology, 3(3), 203-220.

Moler, S. (2002). Stop you're going the wrong way ! http://www.tfhrc.gov/pubrds/02sep/06.htm

Reason, J., Manstead, A., Stradling, S., Baxter, J., Campbell, K.L. (1990). Errors and violations on the roads: A real distinction? Ergonomics, 33 (10/11), 1315-32.

Scaramuzza, G., Cavegn, M. (2007). Wrong way drivers: Extent – Interventions.

Setra. (2008). Rapport d'études : prévention et traitement des prises à contresens, état des connaissances. http://www.setra.developpementdurable.gouv.fr/IMG/pdf/0829w_rapportPreventionContresens.pdf

Van Eslande, P. (2003). Les erreurs des conducteurs âgés. Recherche transports sécurité, 81, 190-202.