safety

Article

Visual Perception and Understanding of Variable Message Signs: The Influence of the Drivers' Age and Message Layout

Gianfranco Fancello [1], Patrizia Serra [1,*] and Claudia Pinna [2]

1 DICAAR—Department of Civil and Environmental Engineering and Architecture, University of Cagliari, 09123 Cagliari, Italy; fancello@unica.it
2 Infrastructure Planning Team, Cumbria County Council, Carlisle CA1 1RD, UK; claudia.pinna@cumbria.gov.uk.com
* Correspondence: pserra@unica.it

Abstract: Variable message signs (VMS) are used to display messages providing up-to-date traffic-relevant information so that drivers can safely adapt their behavior in real time. The information reported in a VMS should be brief but comprehensive to minimize perception time. The latter can be influenced by the way the message is displayed. This study investigates how the different ways of displaying the same message can influence reading time and the information perception process at different driving speeds. Specifically, the following message characteristics are investigated: (i) use of uppercase and lowercase letters; (ii) use of familiar pictograms; and (iii) use of less familiar pictograms. Furthermore, as perception time typically changes with ageing, drivers belonging to three different age classes are tested. The experimentation was performed by simulating a vehicle passing along a straight road upon which a VMS displaying different messages was placed. Experimentation results are analyzed using the Kruskal–Wallis test, Friedman rank-sum test and Welch one-way ANOVA, showing that: (i) the use of uppercase or lowercase does not seem to significantly affect reading times; (ii) the use of pictograms that are not very familiar to habitual road-users can be counterproductive for the perception process; (iii) elderly drivers always have greater difficulty in perceiving the message than young or middle-aged drivers. The findings of this study can be of help for traffic authorities to design the most suitable structure for a VMS so that its information can be unequivocally and immediately conveyed to drivers.

Keywords: variable message signs; driving safety; drivers' visual perception; drivers' age; pictograms; human factors

Citation: Fancello, G.; Serra, P.; Pinna, C. Visual Perception and Understanding of Variable Message Signs: The Influence of the Drivers' Age and Message Layout. *Safety* **2021**, *7*, 60. https://doi.org/10.3390/safety7030060

Academic Editors: Miguel A. Perez and Tom Brijs

Received: 12 May 2021
Accepted: 25 August 2021
Published: 28 August 2021

1. Introduction

The last two decades have seen the increased use on roads of intelligent transport systems designed to facilitate safe driving while reducing driver fatigue and distraction. These include variable message signs (VMS), which provide drivers with information (e.g., on accidents, route choice and congestion) in real time so that they can adapt their behavior accordingly. Compared to fixed road signs, VMS have better potential to provide road users with instantly updated messages on road and traffic conditions. The most important condition for the effectiveness of VMS is that the messages are trusted by the road users, which is fostered by experience of their use in traffic [1]. VMS need to meet two conflicting requirements: maximizing comprehension while minimizing the time required for their perception [2]. Messages should be short yet comprehensive, and reading time needs to be reduced to a minimum. Reading time can be influenced by both the characteristics of the message (color, length, number of rows, number and size of characters, images, abbreviations, etc.) and external factors, such as panel location and driver's characteristics [3,4].

Considerable research efforts, including both objective and subjective methods, have been made to determine what kinds of VMS content and format should be displayed, and drivers' attitudes towards VMS [5–7]. The paper by [8] investigated the effects of diverse factors on drivers' guidance compliance behaviors according to road information shown on VMS, finding that factors such as age, driving years, monthly income, driving style, occupation, and familiarity with road network are significant determinants of guidance compliance behavior. Driver response to information provided by VMS was analyzed in [9] using a multinomial logit model calibrated based on personal socioeconomic characteristics and trip features. More recently, the paper by [10] studied drivers' responses to dynamic travel information with VMS using a classification and regression tree model. The paper by [7] investigated the factors affecting VMS by examining, through a revealed preference questionnaire and stated preference survey, what kinds of VMS contents, formats and their interactions are preferable to Chinese drivers. The results reveal that drivers seem to prefer the information shown in an amber-on-black on text format and a white-on-blue on graph format in foggy weather. The paper by [11] investigated the impact of VMS travel time visualization on travelers' route choice behaviors using a stochastic network equilibrium model. The results show that the optimal design of VMS's locations and travel time display could lead to significant congestion mitigation.

Several researchers have estimated reading times according to message characteristics, such as the number of words and rows, lexicon, and images. In 1979, Jacobs and Cole developed a linear relationship, via regression, between reading time (t) and the number of words (N) included in the message ($t = 0.32\ N - 0.21$) [12]. The influence of the number of words on reading time was also evaluated in [13], according to which drivers can correctly read up to four words (or two units of information) displayed for 0.5 s per word without loss of recall. Subsequently, in 1994, Setra developed a model ($t = N/3 + 2$) that estimates the reading time (t) of a message as a function of the number of words or symbols (N) it comprises [14]. According to the paper by [15], reading times are affected by the length of the message, and messages too long or complicated may lead some drivers to slow down dangerously to read them. In this regard, the paper by [16] analyzed through a medium-fidelity driving simulator the optimum number of units of information VMS should display to influence driver speeding behavior. Their results suggest that, on the one hand, the comprehension time is low when there are fewer units of information, and on the other hand, too little information may be unclear or ambiguous, whereas too much may be hard to understand and cause drivers to slow down. The number of rows used to convey the message is also proven to affect response time. The latter was found to be minimal for messages displayed in two rows [17], while the best results were obtained for up to six words distributed in two rows [18].

The lexicon used to compose the text can also affect reading times; it is always preferable to employ commonly used terms with which drivers are familiar. The language used should also be that of the drivers usually traveling along that road [19]. The words used need to be chosen appropriately, as they affect the comprehension and perception of information [20]. Abbreviations can be included to shorten the length of the message, but they must be used carefully. If abbreviations are unfamiliar to drivers, they can become unintelligible [21] and slow down the information perception process.

Pictograms can be used in VMS to communicate the message graphically and reduce the length of the text message. A pictogram is an ideogram that conveys its meaning through its pictorial resemblance to a physical object or event. Broadly speaking, pictograms have some advantages—they are language-independent and are visible from greater distances than text signs [22]. Compared to text-only messages, pictograms can simplify the understanding process [23,24], but if poorly executed can also impair its understandability and cause interpretative ambiguities [25]. In this regard, the US Manual of Traffic Control Devices (MUTCD) recommends accompanying the ideogram with a text sign when it is not familiar [26]. Although several researchers on traffic signs agree that pictorial information would improve equivalent text messages, the benefits of pictograms in VMS are still a controversial issue. The paper by [27] assessed the difficulties experienced by adults with dyslexia in acquiring the information shown in VMS, providing evidence that the legibility of single-word text messages can exceed that of pictograms in the presence of VMS with a high aspect ratio. Relatively recent studies have shown that the comprehension reaction time for pictograms in fixed road signs may depend on the type of sign [28], but when the symbolic sign is substituted with text, the familiarity becomes irrelevant [29]. Since pictograms alone are sometimes insufficient, supplementary texts can be used. When a combination of a pictogram and text is used, the pictogram should give the most central information, while the text is a complement [1]. In VMS, combined messages (text + pictogram) may act as a unified stimulus and the processing of a pictogram may be influenced by the text and vice versa. Figuring out this process is an area yet to be explored.

Several studies agree that message perception is affected by the characteristics of the drivers (such as age and visual abilities) as much as, if not more than [30], those of VMS. In 2008, a study comparing Italian and American drivers found that older drivers face considerable difficulties in executing some maneuvers, such as merging from a ramp, changing lanes, turning left in non-signalized intersections, and driving at night [31]. Eyesight is the sense most affected by ageing [32]. The characteristics that can affect driving behavior are eye health, visual acuity, range of the useful field of view, color discrimination, depth perception, contrast sensitivity and sensitivity to low light. Older people have a reduced field of vision, their eyes are more sensitive to glare, and movements that occur at the edges of the visual field are not clearly perceived [33]. Elderly drivers need more time to adjust their focus [34], and the minimum duration of fixation needed to discern the details of a signal increases with age [35,36]. A variety of modifications to the visual system, such as anatomical changes that alter visual ability and reduce the amount of light that can reach the retina, occur with age [37]. Eye movements are affected by these physiological changes, and they impair the perception of distance and movement. Because of the physiological decline in visual and cognitive abilities, elderly drivers encounter difficulties in coping with specific driving situations and maneuvers. In 2014, the European Commission estimated that by 2025, over 20% of Europeans will be 65 or older and the number of over eighty-year-olds will rapidly increase. Older people are playing an ever more active role in society, and being able to drive is necessary for their mobility needs.

Understanding how the structure of VMS can affect the perception and understanding process is of fundamental importance to draw practical conclusions on the design and display of effective VMS [38]. It is believed that the effective use of VMS can reduce the risk level of road accidents. The paper by [39] analyzed the effect of anti-speed messages on driving attitudes and traffic speed in an inter-city highway, demonstrating that there are small, albeit beneficial, effects using these messages. The speed management impact of VMS in motorways to reduce the number of accidents and the related risk level was further analyzed in [40].

This study aims to add to the existing body of literature by investigating the extent to which the different ways of displaying the same message on VMS can influence reading times and the information perception process depending on the driver's age and driving speed. Specifically, the impact of the following message characteristics is investigated:

- use of uppercase and lowercase letters
- use of familiar pictograms
- use of less familiar pictograms.

An experimentation was performed in a simulation room reproducing the scene of a vehicle passing along a straight road upon which a VMS displaying different messages is placed. The simulation tests reproduced the typical driving scene viewed by drivers through their visual cone, assuming two different driving speeds: 50 and 80 km/h. Three different age groups (young, middle-aged, and elderly drivers) were involved in the experimentation to investigate how reading times and understanding rates of the various message compositions can change with age.

The structure of the paper is as follows. Section 2 describes the methods and materials used in this experimental study. Section 3 illustrates the quantitative results of the study relating to reading times and the comprehension rate of the various messages for the three age groups. The experimental results are critically discussed in Section 4, along with some considerations on the limitations of the study. Finally, Section 5 concludes the paper.

2. Materials and Methods

This section provides a detailed description of the methods and materials used in this study, including the:

- testing procedure;
- characteristics of the sample of drivers involved in the experimentation;
- features of the eye tracker device used in the experimentation;
- design of the test: definition of text messages and rules adopted for VMS composition; and
- statistical tests used in the analysis of the results.

2.1. Testing Procedure

This research aims to specifically investigate the relationship between the visual stimulus transmitted with a VMS and the related perception process according to the biodynamic model. To this end, the simulation environment for the experiment was set up with the explicit intent to exclude any potential external disturbing factors (traffic, pedestrians crossing, noises, etc.) that could affect reading time. The simulation tests were carried out in a simulation room in the Transport Engineering Laboratory of the University of Cagliari (Cagliari, Italy). The simulation room included a driver's seat and a video projector that broadcast the driving scene on a 3 × 3 m screen (Figure 1).

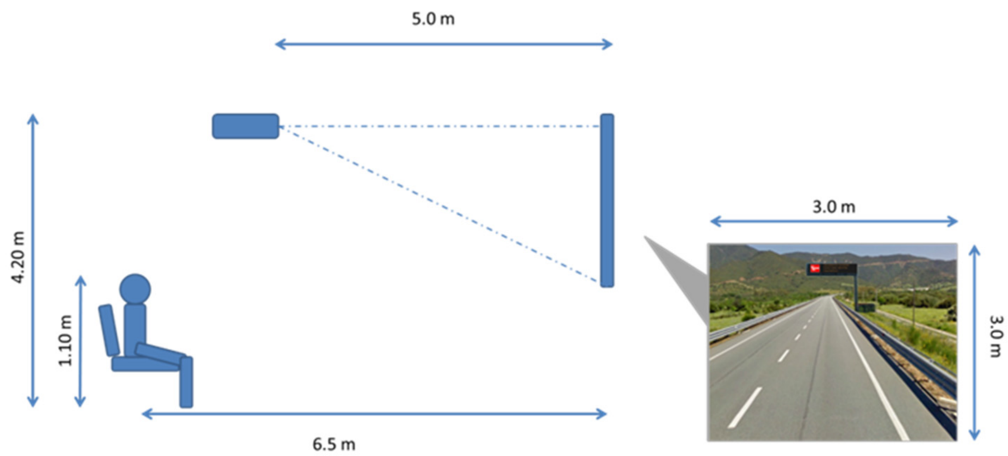


Figure 1. Left: layout of the simulation room. Right: a frame of the broadcasted driving scene.

A typical suburban road scene was created using video editing software. The driving scene simulated a vehicle passing along a straight road upon which a VMS is located (Figure 1—right). To test the reading times under different conditions, each driving scene was displayed for 6″ at a speed of 50 km/h and for 3″ at a speed of 80 km/h. The choice of the two test speeds was linked to the type of road used in the test—that, is a single carriageway with two lanes and two-way traffic, with a speed limit of 80 km/h in force on it. The panel was visible for the whole duration of the video.

2.2. Trial Participants

The tested sample included 30 volunteer drivers aged from 22 to 83 years. The 30 participants were divided into three balanced age groups [41] in order to investigate the role of age in the process of reading and understanding the message: 10 young drivers (less than 40 years old), 10 middle-aged drivers (between 40 and 65 years old) and 10 elderly drivers (over 65 years old). All the participants had a valid driving license and drove regularly. Table 1 shows the general characteristics of the sample.

Table 1. Characteristics of the sample.

		Young Drivers	Middle-Aged Drivers	Elderly Drivers
N. of tested drivers		10	10	10
Mean Age		32	50	68
Min Age		22	41	65
Max Age		40	64	83
Gender	M	7	7	6
	F	3	3	4

Before starting with the experimentation, participants were all informed about the study's full compliance with the national privacy legislation (Regulation EU 2016/679 and Legislative Decree 101/2018) in processing the data and videos collected during the test. All subjects gave their informed consent for inclusion before they participated in the study. The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Ethics Committee of the University of Cagliari (Project identification code: 2021-UNCACLE-0094227).

2.3. The Eye Tracker for the Acquisition of Experimental Data

A portable eye tracker (ASL Mobile Eye by Applied System Laboratory) was used to measure the time spent by the drivers to read the displayed message. The used eye-tracker device has two synchronized micro-cameras: one records the eye movements, by pupil tracking, the other pinpoints the driver's field of vision, recording exactly what he/she is observing (Figure 2).

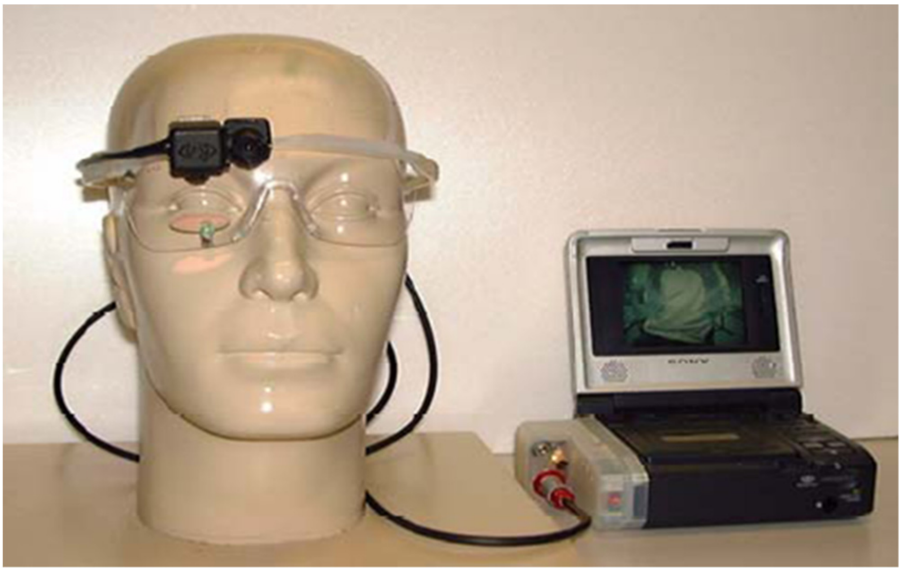


Figure 2. The used eye tracker.

The synchronization of the two cameras allows one to observe, second by second, what the eye sees and for how long. The two cameras produce two outputs:

- a video recording of the scenes observed by the driver
- a matrix with the coordinates of pupil movements and gaze points, both recorded every 0.03 s.

The reading time for the whole message and individual lines was calculated using the "Gaze tracker" software (Eye Response Technologies Inc.: Charlottesville, VA, USA).

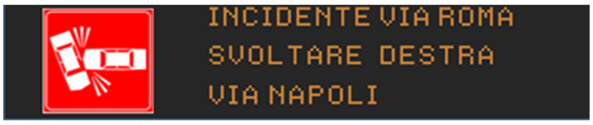
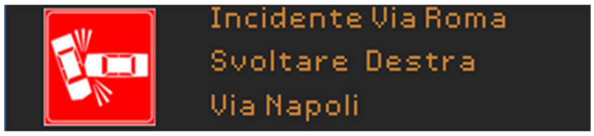
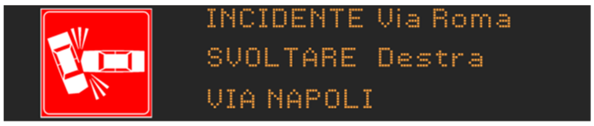
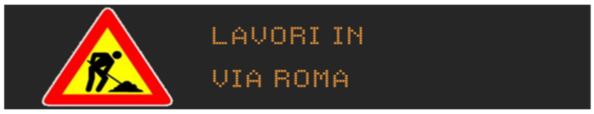
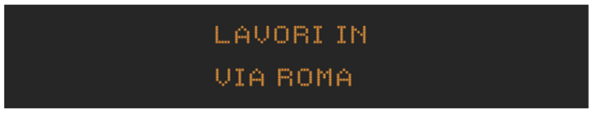
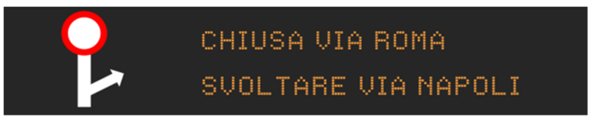
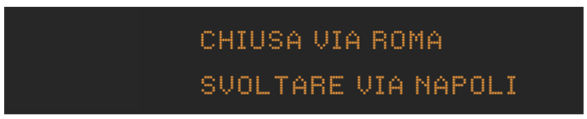
2.4. Message Design

The displayed messages were organized into three different groups to analyze how the reading times of VMS change in relation to the use of:

1. uppercase and lowercase letters (Group 1)
2. familiar pictograms (Group 2)
3. less familiar pictograms (Group 3).

Table 2 summarizes the main characteristics of the three groups of messages analyzed. Messages were written in Italian language to maximize comprehension by volunteer drivers, all of whom were Italian native speakers.

Table 2. Tested message compositions.

Group	ID	Description	Displayed Message
Group 1 Use of uppercase and lowercase letters	1A	All in uppercase	
	1B	All initial letters in uppercase	
	1C	More significant words in uppercase, others capitalized	
Group 2 Use of familiar pictograms	2A	Pictogram replaces part of the text message	
	2B	Pictogram repeats the concept shown in the text message	
	2C	No pictogram	
Group 3 Use of less familiar pictograms	3A	Pictogram replaces part of the text message	
	3B	Pictogram repeats the content of the text message	
	3C	No pictogram	

Each group included, in turn, three different ways of displaying the same content, for a total of nine message compositions. When the message's composition included a pictogram, it was placed on the left-hand side as suggested in the Vienna Convention on road signs and signals [42].

The basic content of the analyzed messages varied for each group (see Table 2):

- Group 1: "Accident in Via Roma—Turn right in Via Napoli"
- Group 2: "Road Works in Via Roma"
- Group 3: "Via Roma Closed—Turn into Via Napoli".

In order to investigate the effect of driving speed on reading time, the simulation tests were performed twice, once assuming a driving speed of 50 km/h and once assuming a speed of 80 km/h. To avoid drivers memorizing the message previously read, road names were changed when performing the test for the second time: "via Roma" and "via Napoli" were replaced by "via Milano" and "via Firenze". Thus, a total of 18 message compositions (corresponding to 18 driving scenes) were submitted to each participant during the simulation test. The 18 scenes were played in the same order for all drivers. The video projection was paused after each scene to allow the participants to illustrate what they read on the just-displayed VMS.

2.5. Statistical Tests Used in the Analysis

To analyze the differences between the three age groups and the different messages displayed, the following statistical tests suitable in the case of small samples were used:

- Bartlett test for homogeneity of variance: the null hypothesis of this test is that the variances are homogeneous.
- Shapiro test to verify if the distribution is normal: the null hypothesis of this test is that the distribution is normal.
- Friedman rank-sum test to compare two or more groups in the case of heteroscedasticity and not-normal distribution. The null hypothesis is that the groups are equal.
- The Wilcoxon signed-rank test is a post hoc test performed after the Friedman rank-sum test. The groups are compared in pairs and the test provides a range. If this range falls within the reference range 8–47, then the pairs have the same characteristic.
- The Kruskal–Wallis test is used in the case of homoscedasticity when the hypothesis of normal distribution is violated. The null hypothesis is that the groups are equal.
- Welch one-way ANOVA is performed if the data are normal and heteroscedastic. The null hypothesis is that the groups are equal.

3. Results

3.1. The Reading Time of the VMS: The Role of Drivers' Age

The reading times for the complete message and the single lines were acquired for each driver at both test speeds (50 and 80 km/h) using the eye tracker. The average reading time per single word was derived as the ratio between the reading time per row and the number of words read in the same row. To proceed with the textual analysis, the text was lemmatized by removing prepositions and articles and imposing three letters as the minimum length of each word. Figure 3 shows the resulting average reading times (s) per word for each of the 30 drivers analyzed. The average reading times of the three age groups are as follows:

- young drivers: 0.63 s per word with a variance of 0.0029; the fastest was driver n.5 (0.55 s), the slowest n.9 (0.73 s)
- middle-aged drivers: 0.64 s per word with a variance of 0.0032; the fastest was driver n.13 (0.58 s), the slowest n.16 (0.78 s)
- elderly drivers: 0.79 s per word with a variance of 0.02367; the fastest drivers were n. 23 and 25 (0.58 s), the slowest n.21 (1.14 s).

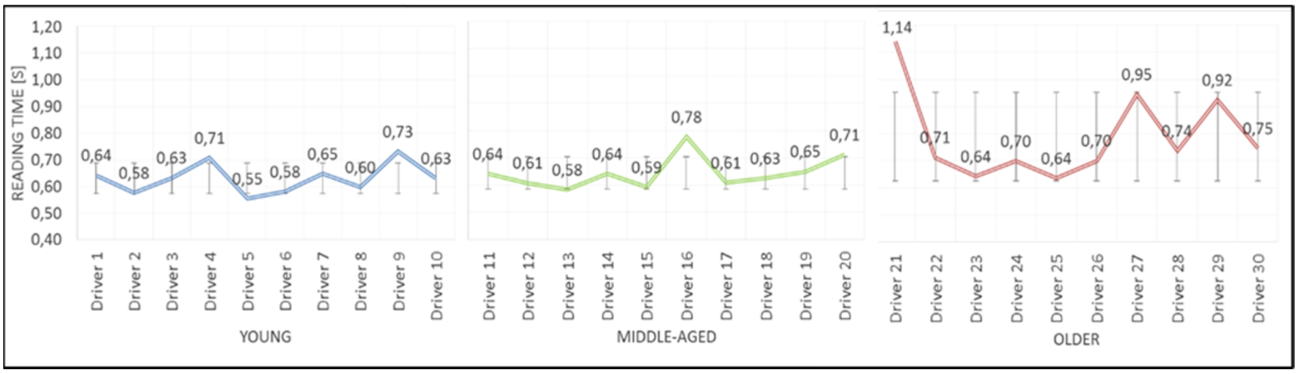


Figure 3. Reading times per word by age group.

Reading times appear similar for young and middle-aged drivers, while they differ widely for elderly drivers. The statistical significance of this result was verified using the tests below:

- Bartlett's test:
  - Bartlett's K-squared = 12.6799, df = 2, p-value = 0.0018.

  The average reading times within the three age groups are not homoscedastic.
- Shapiro's test:
  - Young drivers' reading times: W = 0.9431, p-value = 0.5884;
  - Middle-aged drivers' reading times: W = 0.8585, p-value = 0.0732;
  - Elderly drivers' reading times: W = 0.8304, p-value = 0.0338.

  The reading times of young and middle-aged drivers are normally distributed, while those of elderly drivers are not. Consequently, to evaluate whether there is any significant difference in the average reading times per word within the three age groups, the Friedman rank-sum test was applied.
- Friedman rank-sum test:
  - Chi-squared = 9.8974, df = 2, p-value = 0.0071.

  At least one of the three groups is significantly different.
- The post hoc Wilcoxon signed-rank test was applied to identify the significantly different group by comparing the various groups in pairs. The results are illustrated in Table 3 and show that only the older drivers' reading time per word is significantly different.

Table 3. Results of the Wilcoxon signed-rank test.

Pair Considered	Range (8–47)	Result
Young—Middle-aged	26.5–27.5	NOT significantly different
Young—Elderly	1.5–53.5	Significantly different
Middle-aged—Elderly	5–50	Significantly different

3.2. Group 1—Use of Uppercase and Lowercase Letters

Table 4 details the numerical results of the simulation tests related to Group 1. The table shows for each message composition and each age group the percentage of drivers who understood (totally, partially, not at all) the displayed message and the related reading times, at both 50 and 80 km/h.

Table 4. Numerical results for Group 1—use of uppercase and lowercase letters.

			Young			Middle-Aged			Elderly		
ID	**Item Analyzed**	**Driving Speed (km/h)**	**Message Understood**	**Message Partially Understood**	**Message Not Understood**	**Message Understood**	**Message Partially Understood**	**Message Not Understood**	**Message Understood**	**Message Partially Understood**	**Message Not Understood**
1A	Drivers who understood the message (%)	50	70%	30%		80%	20%		30%	30%	40%
		80	50%	50%		80%	20%		10%	50%	40%
	Reading time per message (s)	50	4.32	2.77		4.16	3.02		3.25	3.10	2.98
		80	2.67	2.58		2.55	2.24		2.41	1.98	1.93
1B	Drivers who understood the message (%)	50	80%	20%		90%	10%		50%	30%	20%
		80	60%	30%	10%	50%	50%		20%	30%	50%
	Reading time per message (s)	50	3.70	2.59		3.76	3.14		3.44	3.72	2.66
		80	2.84	2.38	2.20	2.61	2.07		1.43	2.27	1.81
1C	Drivers who understood the message (%)	50	90%	10%		90%	10%		30%	50%	20%
		80	70%	30%		80%	10%	10%	10%	40%	50%
	Reading time per message (s)	50	3.54	2.38		4.01	3.64		2.67	3.12	1.55
		80	2.55	1.66		2.53	1.60	2.09	2.63	2.47	1.81

As for the comprehension of the various messages when using uppercase and lowercase letters, it emerges that:

- at 50 km/h, young and middle-aged drivers showed similar results. The composition 1C was the most understood in both age groups (90%), 1B was slightly less understood by young drivers, and 1A was somewhat less clear for both groups (it was fully understood by 80% of middle-aged drivers and 70% of young drivers). Understanding rates were significantly lower for elderly drivers, for whom the composition best understood at 50 km/h was 1B (totally understood by 50% of elderly drivers), followed by 1C and 1A (30%)
- at 80 km/h, the results were similar to the previous ones, but the percentage of understood messages decreased. For young and middle-aged drivers, 1C remained the message with the highest rate of understanding (it was totally understood by 70% of young drivers and 80% of middle-aged drivers). The understanding rates of elderly drivers were lower for all three compositions: compositions 1B and 1C were not understood by 50% of elderly drivers, and 1A by 40%.

Focusing on the reading time of the VMS only for the drivers who fully understood the message:

- at 50 km/h, young and middle-aged drivers showed similar and higher reading times than elderly drivers for all message compositions, respectively. Among the tested elderly drivers, the very few who understood the message seemed to read it faster than younger drivers. The composition that was read faster by young and elderly drivers was 1C, while middle-aged drivers appeared to read 1B slightly faster
- at 80 km/h, reading times were lower for all age groups for all three message compositions. Young and middle-aged drivers showed no significant differences in the reading times of the three messages, while the few elderly who understood the message read composition 1B faster.

The statistical validation of the results was performed using the tests below:

- Bartlett's test:
  - Bartlett's K-squared = 9.1632, df = 2, p-value = 0.0102.

  The average reading times in the three age groups are not homoscedastic.
- Shapiro's test:
  - Message 1A W = 0.9585, p-value = 0.2827;

– Message 1B W = 0.9792, *p*-value = 0.8028;
– Message 1C W = 0.9505, *p*-value = 0.1741.

The distribution is normal. To determine whether the average reading times are affected using uppercase and lowercase letters, Welch one-way ANOVA was applied:

– F = 2.3326; num df = 2.000; denom df = 55.028; *p*-value = 0.1066.

The results indicate that the three compositions are not significantly different from one another.

3.3. Group 2—Use of Familiar Pictograms

The numerical results of the simulation tests related to Group 2 are illustrated in Table 5. The table shows for each message composition and each age group the percentage of drivers who understood the displayed message and the related reading times at both 50 and 80 km/h.

Table 5. Numerical results for Group 2—use of familiar pictograms.

			Young		Middle-Aged		Older	
ID	**Item Analyzed**	**Driving Speed (km/h)**	**Message Understood**	**Message Not Understood**	**Message Understood**	**Message Not Understood**	**Message Understood**	**Message Not Understood**
2A	Drivers who understood the message (%)	50	60%	40%	90%	10%	40%	60%
		80	70%	30%	90%	10%	40%	60%
	Reading time per message (s)	50	1.36	1.06	2.19	1.53	1.49	1.76
		80	1.06	1.24	1.33	1.41	1.14	1.27
2B	Drivers who understood the message (%)	50	100%	0%	100%		80%	20%
		80	100%	0%	90%	10%	70%	30%
	Reading time per message (s)	50	2.73		2.52		2.65	1.60
		80	2.17		1.97	1.50	2.09	2.03
2C	Drivers who understood the message (%)	50	100%		100%		90%	10%
		80	100%		100%		80%	20%
	Reading time per message (s)	50	2.97		3.15		3.04	2.43
		80	1.93		1.89		2.07	2.18

The message composition where the pictogram replaces part of the text (2A) was the least understood by all drivers in the three age groups. At 50 km/h, it was understood by 60% of young drivers, 90% of middle-aged drivers, and only 40% of elderly drivers. No significant differences were observed when increasing the driving speed from 50 to 80 km/h. Message compositions 2B and 2C were well understood by almost all young and middle-aged drivers, both at 50 and 80 km/h. The understanding rate dropped slightly for elderly drivers. Message composition 2B was understood by 80% of elderly drivers in the test at 50 km/h (70% at 80 km/h), while 2C was understood by 90% of elderly drivers at 50 km/h, and 80% at 80 km/h.

Leaving aside message composition 2A, which appears to be generally poorly understood, and focusing only on the reading times of the two best-understood compositions (2B and 2C), it emerges that at 50 km/h, the composition with the pictogram was read faster than the one without, though the text is identical.

Reading times at 50 km/h were:

– 2.73 s with the pictogram (2B) and 2.97 s without (2C), for young drivers
– 2.52 s with the pictogram (2B) and 3.15 s without (2C), for middle-aged drivers
– 2.65 s with the pictogram (2B) and 3.04 s without (2C), for older drivers.

Conversely, at 80 km/h, reading times were shorter for the composition without the pictogram (2C):

– 2.17 s with the pictogram (2B) and 1.93 s without (2C), for young drivers

– 1.97 s with the pictogram (2B) and 1.89 s without (2C), for middle-aged drivers
– 2.09 s with the pictogram (2B) and 2.07 s without (2C), for older drivers.

Such results may suggest that while at slower speeds drivers look at both the pictogram and the text, at higher speeds, they focus their attention on the text, thus reading the composition without the pictogram faster.

The statistical validity of the results was investigated as follows:

- Bartlett's test:
  - Bartlett's K-squared = 4.9338, df = 2, *p*-value = 0.0848.

  The average reading time in the groups is not homoscedastic.
- Shapiro's test:
  - 2A W = 0.8243, *p*-value = 0.0002;
  - 2B W = 0.9506, *p*-value = 0.1760;
  - 2C W = 0.9332, *p*-value = 0.0599.

  The results suggest that the distribution is not normal. The Kruskal–Wallis test was then applied to determine whether the average reading times of the message were affected by using the pictogram.
- Kruskal Wallis test:
  - Chi-squared = 47.4938, df = 2, *p*-value = 4.862×10^{-11}.

  The three message compositions are significantly different from one another.

3.4. Group 3—Use of Unfamiliar Pictograms

The third group of messages is structured similarly to the second, with the difference being that the tested pictogram is not a common pictogram that will be immediately recognized, but a less familiar pictogram derived from the combination of two road signs: a no-entry sign and a sign of permitted directions. When this unfamiliar pictogram is displayed in the VMS, the driver's response differs in several aspects from that seen in the previous group. Table 6 details the numerical results of the simulation tests related to Group 3; the structure of the table is the same as that of the previous ones.

Table 6. Numerical results for Group 3—use of unfamiliar pictograms.

			Young			**Middle-Aged**			**Older**		
ID	**Item Analyzed**	**Driving Speed (km/h)**	**Message Understood**	**Message Partially Understood**	**Message Not Understood**	**Message Understood**	**Message Partially Understood**	**Message Not Understood**	**Message Understood**	**Message Partially Understood**	**Message Not Understood**
3A	Drivers who understood the message (%)	50	40%	50%	10%	80%	10%	10%	10%	30%	60%
		80	40%	50%	10%	80%	10%	10%	30%	0%	70%
	Reading time per message (s)	50	2.96	2.98	2.65	3.16	3.07	3.60	3.60	3.53	3.11
		80	2.01	2.01	1.86	1.82	1.70	2.10	2.16	0.00	1.90
3B	Drivers who understood the message (%)	50	100%			80%	20%		60%	10%	30%
		80	70%	30%		80%	20%		20%	30%	50%
	Reading time per message (s)	50	2.95			3.38	3.81		3.26	3.51	2.19
		80	2.31	2.57		2.02	1.84		2.41	2.21	2.00
3C	Drivers who understood the message (%)	50	100%			90%	10%		60%	10%	30%
		80	70%		30%	80%		20%	10%	50%	40%
	Reading time per message (s)	50	2.47			2.65	3.11		2.70	2.34	2.83
		80	2.26		2.15	2.00		1.71	2.14	1.61	1.50

Similarly to what emerged in Group 2, the message composition where the pictogram replaces part of the text (3A) was the least understood: only 40% of young drivers, 80% of middle-aged drivers and 10% (30% in the test at 80 km/h) of elderly drivers understood the message correctly. Message compositions 3B and 3C were, on average, better understood by all age groups and showed similar understanding rates. At 50 km/h, message composition 3B was fully understood by 100% of young drivers, 80% of middle-aged drivers and 60% of elderly drivers. Understanding rates of young and elderly drivers dropped, respectively, to 70% and 20% in the test at 80 km/h. Similar values characterize message composition 3C, which at 50 km/h was fully understood by 100% of young drivers, 90% of middle-aged drivers and 60% of elderly drivers. Even in this case, understanding rates dropped when performing the test at 80 km/h, reaching the value of 70% for young drivers, 80% for middle-aged drivers and 10% for elderly drivers. Leaving aside message composition 3A, which appears to be generally poorly understood, the reading times of compositions 3B and 3C are compared to investigate the potential distracting effect of an unfamiliar pictogram in the VMS.

Reading times at 50 km/h were:

- 2.95 s with the pictogram (3B) and 2.47 s without (3C), for young drivers
- 3.38 s with the pictogram (3B) and 2.65 s without (3C), for middle-aged drivers
- 3.26 s with the pictogram (3B) and 2.70 s without (3C), for older drivers.

At 80 km/h, reading times were:

- 2.31 s with the pictogram (3B) and 2.26 s without (3C), for young drivers
- 2.02 s with the pictogram (3B) and 2.00 s without (3C), for middle-aged drivers
- 2.41 s with the pictogram (3B) and 2.14 s without (3C), for older drivers.

According to these results, the presence of a less unfamiliar pictogram slows down reading times for all age groups in both tests.

The statistical significance of such results was investigated as follows:

- Bartlett's test:
  - Bartlett's K-squared = 6.3796, df = 2, *p*-value = 0.04118.

  The average reading time in the three groups is not homoscedastic.
- Shapiro's test:
  - 3A W = 0.9374, *p*-value = 0.0773;
  - 3B W = 0.9684, *p*-value = 0.4971;
  - 3C W = 0.9604, *p*-value = 0.3162.

  The distribution is normal, to determine whether average reading times are affected using an uncommon pictogram, the Welch one-way Anova test was applied:
  - F = 14.7661, num df = 2.0, denom df = 55.543, *p*-value = 7.202×10^{-6}.

  The three messages are significantly different from one another.

4. Discussion

The purpose of this study was to assess the extent to which some features of VMS may influence reading times and understanding rates and whether this can be affected by drivers 'age and driving speed. Table 7 summarizes the main statistical results concerning the performed experimental tests.

The results of the performed experimentation indicate that drivers' age does play a role in the perception of VMS. Elderly drivers generally found greater difficulty in perceiving the displayed message correctly and showed longer reading times per word. Furthermore, while reading times are quite similar for young and middle-aged drivers (their mean values and variance are both very close), the reading times of elderly drivers differ substantially from the other two age groups.

Although the differences between older drivers and the other two age groups may appear small, they can play a relevant role in message understanding. Looking at the "Drivers who understood the message" variable, older drivers always show the worst result. It is worth noting that the VMS is a complex device, in which the drivers must be able to read text and pictures at the same time, usually in a very short timeframe. The reading speed of older drivers is slightly slower than other drivers (there are little but significative differences in reading times among the three age groups), and this is reflected in the lower rate of understanding of the message for the same display time.

Table 7. Statistical test results.

Item	Normal Distribution	Homoscedasticity	Statistical Test	Result
Average reading time per word	No	No	Friedman rank sum test; Wilcoxon signed rank test	Older drivers have significantly different reading times
Uppercase and lowercase characters	Yes	No	Welch one-way ANOVA	The three message compositions are NOT significantly different from one another
Familiar pictogram in conventional position	No	Yes	Kruskal–Wallis test	The three message compositions are significantly different from one another
Less familiar pictogram in conventional position	Yes	No	Welch one-way ANOVA	The three message compositions are significantly different from one another

As for the use of uppercase and lowercase letters, although the experimentation did not highlight significant differences from a statistical point of view regarding the three compositions tested, some considerations can be made.

The message with all words in uppercase is the least well-perceived by all three age groups. This indicates that using all capital letters in dense messages such as the one tested (seven words spread over three lines) makes it more difficult to recognize the words and therefore understand the message. This result is in line with previous studies according to which VMS should use messages with all capital letters only in the presence of a few words and spaced writing (e.g., “WEATHER ALERT”) [43,44].

The message composition in which the significant words are in uppercase seems to be slightly better perceived by young and middle-aged drivers: it allows them to immediately recognize the most significant words, speeding up the understanding of the message content. Conversely, elderly drivers who generally show lower understanding rates of the displayed messages seem to better perceive the composition in which all initial letters are in uppercase. This can mean that they need to read every word to understand the content of the message, which leads to longer reading times.

When increasing the driving speed from 50 to 80 km/h, the percentage of understood messages decreases for all age groups as well as reading times.

Some interesting elements emerged on the effects of a pictogram in the panel in terms of conveying the message. Pictograms are supposed to speed up the comprehension of VMS because they graphically introduce the issue (traffic jam, road works, queue, etc.) and in some way anticipate the words reported in the text to the drivers. When a pictogram replaces part of the text, whether it is familiar or not (compositions 2A and 3A), the message is generally less understood by all age groups. Such results seem to suggest that the pictogram should not replace part of the text, but it should eventually be used to reinforce the concept expressed in the written text. In this regard, it should be noted that when a pictogram is used to repeat the same concept expressed in the text, different comprehension rates and reading times are recorded depending on whether the used pictogram is more or less familiar. At 50 km/h, a familiar pictogram repeating the same information expressed in the written text (2B) helps to capture the message faster than the VMS composition without a pictogram (2C), and this applies for all age groups. On the other hand, when the pictogram used is less familiar, an increase in reading times and a reduction in the understanding rate compared to the text-only composition are recorded for all age-groups. It should be emphasized that effectiveness of the pictogram is based on its recognizability. If this latter is lacking, drivers are disoriented and need more time to read the message, and thus understanding it becomes more difficult.

Such experimental results suggest that paying attention to the way in which pictograms are used in VMS. Although, on the one hand, the presence in a VMS of a familiar and commonly used pictogram can help drivers to capture the meaning of the message better and faster, on the other hand, a less familiar pictogram can be confusing and can slow down the understanding process, despite the apparent simplicity of its message.

The research described has some limitations related to the simulation environment in which it was conducted. The experimentation was performed in a research laboratory where participants had to passively observe the road scene being projected on a screen. In order to focus on the relationship between the visual stimulus and its perception according to the biodynamic model, the simulation environment was set up with the explicit intention of excluding any external disturbing factors that could influence the reading and perception time. Although, on the one hand, this allowed us to focus on the biodynamic perception aspect, on the other hand, it does not reproduce the real driving conditions, where the driver's attention is instead divided between different activities and stimuli and not focused on a single element. For this reason, the results of this research are not intended to be directly transferable to real driving situations, but they have the potential to support more effective composition of information messages on VMS.

5. Conclusions

This study has investigated, by means of an objective method based on a simulation experiment, the extent to which some features (use of uppercase and lowercase letters and of familiar and less familiar pictograms) of the messages displayed in VMS may influence reading time and understanding rates and whether and how these latter factors can be affected by the driver's age and driving speed.

The driver's age was confirmed to play a key role in the visual perception of VMS. Elderly drivers showed a longer reading time and greater difficulty in correctly perceiving the message than young and middle-aged drivers. This result is not surprising, as ageing typically causes deterioration of vision and a reduction in visual acuity, thus reducing the ability to capture the fine details of a visual stimulus, such as the text displayed in a VMS.

An interesting finding of this study concerns the use of pictograms in VMS. Although pictograms are generally supposed to simplify and speed up the perception process, the experimentation results show that they may instead slow it down depending on the clarity and recognizability of the pictogram itself. In fact, for the visual stimulus to be useful, it must be understandable in a simple and immediate way. In this experimentation, less familiar pictograms are in fact proven to produce a lengthening of the perceptual process, probably due to the increased time needed to interpret the object within the panel.

Despite some of the limitations that this research may have, related to the laboratory environment where the tests were performed, the findings offer a contribution to the research to identify more preferable VMS formats, and could be of help for traffic authorities to design the most suitable structure for a VMS so that its information can be displayed in an understandable and effective way, with positive repercussions for traffic efficiency and safety. As a further development of the research, the use of a physical driving simulator to reproduce the test would likely improve the strength of the results and their transferability to the real context.

Author Contributions: Conceptualization, G.F., P.S. and C.P.; methodology, G.F., P.S. and C.P.; software, C.P.; validation, G.F. and P.S.; formal analysis, G.F., P.S. and C.P; investigation, G.F., P.S. and C.P.; writing—original draft preparation, C.P.; writing—review and editing, G.F. and P.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Ethics Committee of the University of Cagliari (Protocol Code: 2021-UNCACLE-0094227; date of approval 5 May 2021).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study. The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Ethics Committee of the University of Cagliari (Project Identification Code: 2021-UNCACLE-0094227).

Data Availability Statement: The data supporting the reported results are available upon reasonable request to the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Nygårdhs, S.; Helmers, G. *Vms-Variable Message Signs: A Literature Review*; Swedish National Road and Transport Research Institute: Linköping, Sweden, 2007.
2. Dutta, A.; Fisher, D.L.; Noyce, D.A. Use of a driving simulator to evaluate and optimize factors affecting understandability of variable message signs. *Transp. Res. Part F Traffic Psychol. Behav.* **2004**, *7*, 209–227. [CrossRef]
3. Williams, B.; Gibbons, R.; Medina, A.; Connell, C. Visibility of a color variable message sign in the fog. In *94 Annual Meeting Transportation Research Board*; National Academic: Washington, DC, USA, 2015.
4. Fancello, G.; Carta, M.G.; Bresciani, N.; Maternini, G.; Fadda, P. *Modalità di Invio delle Informazioni e la Percezione Dell'automobilista: Un'analisi Sperimentale sui Pannelli a Messaggio Variabile*; T&T. Transport and Territory: Milan, Italy, 2007; Volume 20, pp. 59–72. ISSN 1723-7432.
5. Lai, C.J. Drivers' comprehension of traffic information on graphical route information panels. *Accid. Anal. Prev.* **2012**, *45*, 565–571. [CrossRef] [PubMed]
6. Ronchi, E.; Nilsson, D.; Modig, H.; Walter, A.L. Variable Message Signs for road tunnel emergency evacuations. *Appl. Ergon.* **2016**, *52*, 253–264. [CrossRef] [PubMed]
7. Zhao, W.; Quddus, M.; Huang, H.; Lee, J.; Ma, Z. Analyzing drivers' preferences and choices for the content and format of variable message signs (VMS). *Transp. Res. Part C Emerg. Technol.* **2019**, *100*, 1–14. [CrossRef]
8. Zhong, S.; Zhou, L.; Ma, S.; Jia, N.; Wang, X. Guidance compliance behaviors of drivers under different information release modes on VMS. *Inf. Sci.* **2014**, *289*, 117–132. [CrossRef]
9. Ma, Z.; Shao, C.; Song, Y.; Chen, J. Driver response to information provided by variable message signs in Beijing. *Transp. Res. Part F Traffic Psychol. Behav.* **2014**, *26*, 199–209. [CrossRef]
10. Chang, A.; Wang, J.; Jin, Y. Driver Compliance Model Under Dynamic Travel Information with ATIS. In *Information Technology and Intelligent Transportation Systems*; Springer: Cham, Switzerland, 2017; pp. 201–212.
11. Li, M.; Lin, X.; He, F.; Jiang, H. Optimal locations and travel time display for variable message signs. *Transp. Res. Part C Emerg. Technol.* **2016**, *69*, 418–435. [CrossRef]
12. Jacobs, R.J.; Cole, B.L. Acquisition of information from alphanumeric road signs. In Proceedings of the 9th Australian Road Research Conference, Brisbane, Australia, 21–25 August 1978; Volume 9, pp. 390–395.
13. Dudek, C.L.; Huchingson, R.D.; Williams, R.D.; Koppa, R.J. *Human Factors Design of Dynamic Visual and Auditory Displays for Metropolitan Traffic Management*; Volume 2-Dynamic Visual Displays (No. FHWA-RD-81-40 Final Report); Texas Transportation Institute: Arlington, TX, USA, 1981.
14. SETRA. *Panneaux de Signalisation a Messages Variables*; SETRA: Provins, France, 1994.
15. Castro, C.; Horberry, T. (Eds.) *The Human Factors of Transport Signs*; CRC Press: Boca Raton, FL, USA, 2004.
16. Banerjee, S.; Jeihani, M.; Khadem, N.K.; Brown, D.D. Units of information on dynamic message signs: A speed pattern analysis. *Eur. Transp. Res. Rev.* **2019**, *11*, 15. [CrossRef]
17. Lai, C.J. Effects of color scheme and message lines of variable message signs on driver performance. *Accid. Anal. Prev.* **2010**, *42*, 1003–1008. [CrossRef] [PubMed]
18. Hitchins, D.; Brown, T.; McCoy, D.; Quinton, M.; O'Halloran, M.; Plewes, M. Lowercase font set development for Variable Message Signs (VMS). In Proceedings of the 8th World Congress on Intelligent Transport Systems ITS America, ITS Australia, ERTICO (Intelligent Transport Systems and Services-Europe), Sydney, Australia, 30 September–4 October 2001.
19. Dudek, C.L. Changeable Message Sign Operation and Messaging Handbook. Federal Highway Administration, Operations Office of Travel Management. 2004. Available online: http://tmcpfs.ops.fhwa.dot.gov (accessed on 20 May 2019).
20. Fancello, G.; Carta, M.G.; Fadda, P. *Un'analisi Sperimentale Sulle Modalità di Composizione dei Testi nei Pannelli a Messaggio Variabile (PMV)*; T&T. Transport and Territory: Milan, Italy, 2009; Volume 22, pp. 2–13, ISSN 1723-7432.
21. Mavrogeorgis, T.; Bonaldo, A.; Faccio, G.; Ferrante, E.; Remeijn, H.; Pauzie, A.; Balz, W.; MacLaverty, K.; Luoma, J.; Rama, P. Text and combined reference manual. Traffic optimization by the information of integration and control—TROPIC deliverable D05.3. Birmingham, U.K.: Ws. Atkins Consultants. In *The Human Factors of Transport Signs*; Castro, C., Horberry, T., Eds.; CRC Press: Boca Raton, FL, USA; Taylor & Francis Group: London, UK, 1998; ISBN 0-415-31086.
22. Kline, T.J.B.; Ghali, L.M.; Kline, D.W.; Brown, S. Visibility distance of highway signs among young, middle-aged, and older observers: Icons are better than text. *Hum. Factors* **1990**, *32*, 609–619. [CrossRef]
23. Magurno, A.B.; Wogalter, M.S.; Kohake, J.R.; Wolff, J.S. Iterative test and development of pharmaceutical pictorials. In Proceedings of the 12th Triennial Congress of the International Ergonomics Association, Toronto, ON, Canada, 15–19 August 1994; Volume 4, pp. 360–362.
24. Bartłomiejczyk, M. Text and image in traffic signs. *Linguist. Sil.* **2013**, *34*, 111–131.

25. Booher, H.R. Relative comprehensibility of pictorial information and printed words in proceduralized instructions. *Hum. Factors* **1975**, *17*, 266–277. [CrossRef]
26. Federal Highway Administration. *Manual on Uniform Traffic Control Devices*; US Department of Transportation: Washington, DC, USA, 2009. Available online: https://mutcd.fhwa.dot.gov/kno_2009r1r2.htm (accessed on 25 March 2020).
27. Roca, J.; Insa, B.; Tejero, P. Legibility of text and pictograms in variable message signs: Can single-word messages outperform pictograms? *Hum. Factors* **2018**, *60*, 384–396. [CrossRef] [PubMed]
28. Sharples, S.; Shalloe, S.; Burnett, G.; Crundall, D. Journey decision making: The influence on drivers of dynamic information presented on variable message signs. *Cogn. Technol. Work* **2016**, *18*, 303–317. [CrossRef]
29. Shinar, D.; Vogelzang, M. Comprehension of traffic signs with symbolic versus text displays. *Transp. Res. Part F Traffic Psychol. Behav.* **2013**, *18*, 72–82. [CrossRef]
30. Kim, T.; Oh, C.; Yeon, J.Y.; Kim, S. Estimation of message reading time for Variable Message Signs, Dept. of Advanced Transportation Research, The Korea Transport Institute. In Proceedings of the 88th Annual Meeting of the Transportation Research Board (TRB), Washington, DC, USA, 11–15 January 2009.
31. Fancello, G.; Stamatiadis, N.; Pani, E.; Fadda, P. Are Older Drivers different in the US and Italy? In Proceedings of the "Urban Transport XIV", Malta, 1–3 September 2008.
32. Kline, D.W.; Scialfa, C.T. Sensory and perceptual functioning: Basic research and human factors implications. In *Handbook of Human Factors and the Older Adult*; Fisk, A.D., Rogers, W.A., Eds.; Academic Press: San Diego, CA, USA, 1997; pp. 27–54.
33. Crassini, B.; Brown, B.; Bowman, K. Age-related changes in contrast sensitivity in central and peripheral retina. *Perception* **1988**, *17*, 315–332. [CrossRef] [PubMed]
34. Butler, K.M.; Zacks, R.T.; Henderson, J.M. Suppression of reflexive saccades in younger and older adults: Age comparisons on an antisaccade task. *Mem. Cogn.* **1999**, *27*, 584–591. [CrossRef] [PubMed]
35. Dewar, R.E.; Kline, D.W.; Swanson, H.A. Age differences in comprehension of traffic sign symbols. *Transp. Res. Rec.* **1994**, 1456. Available online: https://trid.trb.org/view/425281 (accessed on 25 March 2020).
36. Fancello, G.; Pinna, C.; Fadda, P. *The Vision of Roundabout by Elderly Drivers. Advances in Human Aspects of Road and Rail Transportation*; CRC Press: Boca Raton, FL, USA; Taylor & Francis Group: Oxfordshire, UK, 2012; p. 459, ISBN 13: 978-0-9796435-5-2; ISBN 10: 0-9796435-5-4.
37. Eby, D.W.; Trombley, D.A.; Molnar, L.J.; Shope, J.T. The Assessment of Older Drivers' Capabilities: A Review of the Literature. The University of Michigan Transportation Research Institute, Project Report. 1998. Available online: https://deepblue.lib.umich.edu/handle/2027.42/1245 (accessed on 21 April 2020).
38. Erke, A. Effects of variable message signs (vms) on driver attention and behavior. In Proceedings of the European Transport Conference (ETC) 2006, Strasbourg, France, 18–20 September 2006.
39. Tay, R.; De Barros, A. Effectiveness of Road Safety Messages on Variable Message Signs. *J. Transp. Syst. Eng. Inf. Technol.* **2010**, *10*, 18–23. [CrossRef]
40. Oskarbski, J.; Kamiński, T.; Kyamakya, K.; Chedjou, J.C.; Żarski, K.; Pędzierska, M. Assessment of the speed management impact on road traffic safety on the sections of motorways and expressways using simulation methods. *Sensors* **2020**, *20*, 5057. [CrossRef] [PubMed]
41. Nussbaum, J.F.; Coupland, J. (Eds.) *Handbook of Communication and Aging Research*; Routledge: London, UK, 2004.
42. United Nations. Vienna Convention on Road Signs and Signals (Version 2006). 1968. Available online: https://www.unece.org/fileadmin/DAM/trans/conventn/Conv_road_signs_2006v_EN.pdf (accessed on 22 April 2020).
43. Fancello, G.; Carta, M.G.; Fadda, P. An experimental evaluation of text reading for Variable Message Signs an Italian case study. In *External Costs of Transport Systems: Theory and Applications—Selected Papers*; Crisalli, U., Cipriani, E., Fusco, G., Eds.; Franco Angeli: Milan, Italy, 2013; pp. 126–141, ISBN 978-88-204-4603-1.
44. Fancello, G.; Pinna, C.; Fadda, P. Percezione visiva dei pannelli a messaggio variabile (PMV): Stima di un modello di previsione dei tempi di lettura. In *Segnaletica e Informazione Nelle Strade per il Miglioramento della Sicurezza*; Quaderno n 9 EGAF Edizioni: Forlì, Italy, 2014; pp. 53–61, ISBN 978-88-8482-566-7.