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REMARKS ON THE ROLE OF VISUAL CONTRAST BETWEEN PAVEMENT AND HORIZONTAL MARKINGS IN THE CORRECT INTERPRETATION OF THE ROAD LAYOUTS

Marco Pasetto, Stefano Damiano Barbati

University of Padua, Department of Civil, Environmental and Architectural Engineering, Padua, Italy

ABSTRACT

Road accidents can be determined, among other reasons, by a wrong layout design. An aberration of the visual perspective and losses of visibility due to road geometry (obstacles, variations of the horizontal alignment or section, etc.) can be, together with weather and environmental aspects, the cause of inappropriate behaviors of drivers. The environment is characterized by different factors, road pavement and horizontal markings included. The contrast between their surfaces is an optical requisite for a correct perception of the road lane size and layout. It can be studied on site, but also by means a virtual environment. This paper presents some research experiences set up in 3D virtual environment on the basis of full immersive driving simulation. Layout and pavement materials of an existing road have been reproduced. Road markings consist of lines having different shape, color and size. The wearing course can be varied according to its texture. The experimentation consists in the evaluation of drivers' behavior (trajectory, speed and acceleration) in initial conditions of maximum visual contrast and daytime, and successive phases where the perception of the road surface is changed by means of different stimuli. The goal is the recognition of the role of visual contrast between markings and pavement in the correct interpretation of the road layout.

Keywords: safety, texture, markings, layout, visual contrast

1. INTRODUCTION

In the recent years, the road vehicle has undergone a dramatic technological evolution. The automotive research sector has seen an exponential increase of the functions included in the vehicles [1] [2]. Many researchers and manufacturers have given their contribution to this evolution with different roles and competences [3] [4] [5] [6]. In this course all follow a single main objective: to guarantee an optimization of the interaction between man, vehicle and infrastructure.
The features that determined the greatest results on the vehicle are the electronics ones. These products are already implemented in newer vehicles, while others are being studied. It must be mentioned for example the development of navigation systems (e.g. systems linked to GPS and GNSS), those for the control of the guide and the interaction with the road, the traffic information in real time, the control of the comfort and stability the vehicle, and active safety systems.
Systems that control the speed today are connected to a wide range of schemes that simplify some of the most difficult driving tasks (e.g. parking) or reduce environmental conditioning (e.g. fog, night driving). Many of these functions need to be connected together to provide best results, even if in many cases turn out to be only distractions [7] [8]. For instance, today is possible to adjust the suspension response as a function of speed, or change the steering and the lights in relation to climatic conditions. For this reason, one of the main challenges of the automotive industry is to develop a global electronic architecture of the vehicle to facilitate the integration of different electronic subsystems.
Among all the functions that can be listed, the most discussed are those that directly involve the human factor. This is because while we are driving, we take decisions. Most of these decisions are taken unconsciously. Most of the time, we drive between experience and memory of things already done. However, when we want to program automated systems to perform these operations, we must first of all understand them in detail.
In several areas, the researchers believe they can develop a significant contribution for the safety and driving comfort. In some cases they specialize in analyzing the performance of the vehicle. In some specific conditions, models have been developed that describe the behavior of vehicles (cars and SUVs) on the highway, without a driver, in order to eliminate the human factor. All this is possible now, because we can reconstruct the position of the vehicle in the infrastructure, with cameras that recognize the signs or laser scanners which determine the distance from reference points in the road.
A lot has been written about driving behavior, both with ergonomic and mechanical perspective. In the area of civil engineering the issue is controversial; in short, the choice of driving behavior concerns the trajectory and speed. The first factor is geometrical itself and it can be solved in stochastic way with a good design of the road layout [9]. In the infrastructure sector, the roads are designed with the aim to facilitate the stability of vehicles and guarantee the perspective view of the external environment. The designer studies the geometry (the sequence of straights and curves), defining the speed in order to ensure high standards of safety and ride comfort. The user of the road, however, interprets the layout. In most cases, he uses the available space to adopt behaviors that are inconsistent with the choices of the designer. Speed is the predominant factor in design, that is the parameter to be used in the study of the effectiveness of each proposed solution. It can be studied in different possible contexts, real as well as virtual ones. In most cases the rate becomes the centre of models or algorithms that allow to evaluate the congruence of a road project, vehicle stability, comfort, the effectiveness of a sign or the respect of the rules of driving.
In the present study, the authors describe an experiment which consists in the evaluation of drivers' behavior (trajectory, speed and acceleration) in different visual conditions: at the beginning, with optimum visual contrast in daytime; later, with a worse road surface perception due to a loss of contrast between road marking and bituminous pavement. The goal is the recognition of the role of markings and pavement texture in the correct interpretation of the road layout.

2. METHOD

The study presented by the authors is part of a research project [10] [11] which aims to analyze people's reactions to different visual stimuli and prospective during the driving. It is part of a testing protocol that provides 16 driving tests in a virtual environment. Each person undergoes the full protocol at two different times, after adequate training. Each subject is submitted to a limited number of tests of short duration, in order to avoid a storing of the road layouts and minimize the fatigue. Each test takes less than a minute on average; the experiment does not engage more than 20 minutes each subject.

2.1 The driving simulator test

Each subject undergoes a preliminary 2-minutes trial. This is necessary to create a relationship between the subject and the simulator. The main phase of the experiment consists of two steps. In the first one (Test no. 1) a 1,200 m route in free driving conditions is covered. The room is illuminated with diffused light that simulates daylight (Figure 1a). The second one (Test no. 2) takes place in the same site and under the same environmental conditions, but the contrast between road markings and pavement is reduced (Figure 1b). This scenario decreases the capacity of the driver to read the layout and to adopt the correct trajectory, making the test more challenging. In both cases, the pavement has a bituminous wearing course and micro/macro-texture typical of a close textured surface.

A device detects when the 50 km/h speed is exceeded, while the environment control software constrains the maximum speed at 110 km/h. The warning signal is based on a visual stimulus: the speed indicator turns red. The subject is informed of the operational limit only at the beginning of the test (when it is planned); the two tests can be alternated in the order of execution. At the end of each test several parameters are given by the simulator: trajectory, driving speed, acceleration, steering angle, percentage of use of the brake and accelerator. These values are sampled in intervals of time equal to 3 ms. The information must be related to the distance traveled; for this reason, each test is characterized by a finite number of points of the road axis. The points are 10 meters apart: for this reason, the values are the average of the data collected around the reference point, at a maximum distance of 5 m.

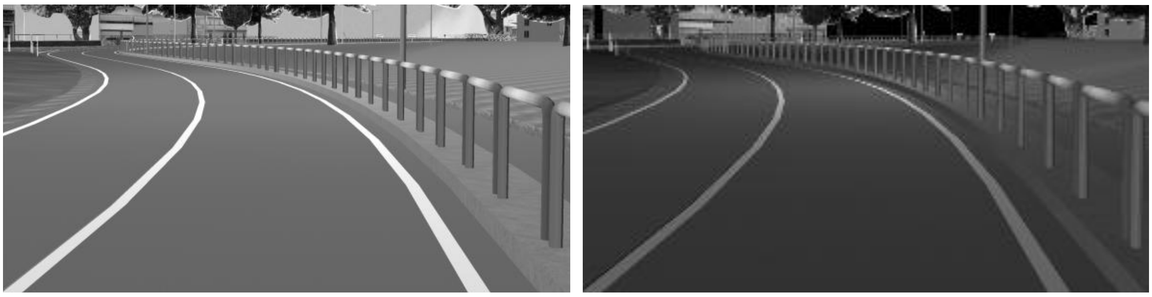

Figure 1. The 3D Virtual Environment: (a) maximum contrast; (b) loss of contrast.

2.2 The virtual environment

The environment used for this experiment has been chosen in a wider research project. The full description of its geometry and construction details has been presented in other published papers [9], [10]. The horizontal alignment can be represented with two long straights connected by a complex sequence of curves (see Figure 2). The route is 1200 m long and not includes transition curves. In the final part, the virtual road is completed by 2 straights which are used to complete and give continuity to the layout.
The visual stimuli placed along the road are actually present. Other vehicles are excluded from the simulation. The environment is fully furnished: road signs integrate visual stimuli of the infrastructure. Along the route, road signs indicating a 50 km/h speed limit are positioned.

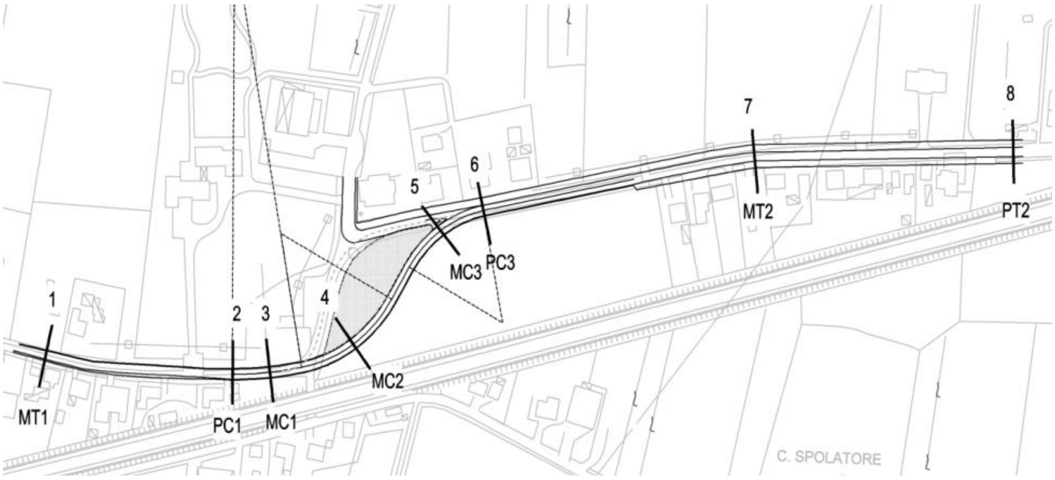

Figure 2. Road Layout

2.3 Subjects

27 volunteers were selected for driving in the virtual environment from all the subjects who participated in the research project. They have an average age of 25.3 years (SD = 4.8), including 18 males and 9 females. The distribution of gender and age are consistent with the population of persons examined in the whole project (mean age 24.8 years SD = 4.47, of which 68.3% are male and 31.7% females).
All volunteers were instructed about the test and the nature of the research. Each subject signed a consent form for the statistical processing of data. A driving test to evaluate the confidence with virtual reality was preliminarily executed. All volunteers were asked to drive in all environments in random order, in both directions of travel. The subjects who participated in the research project and this experiment were identified by a code, that allowed to associate, anonymously and uniquely, each test to each subject. The tests could be repeated at different times and can at the end traced to the same subject.

3. RESULTS

A statistical analysis of the results was conducted on both tests of the experiment. The analysis is extended to all points of the route and over the entire length of 1200 m. The data were represented in a global diagram. Figure 3 shows an exemplification graph of operating speeds in the Test no. 1: in this case, speed is freely selected by the user and the speed limits are indicated by the (vertical) signs only. It means that there is a visual stimulus external to the vehicle.

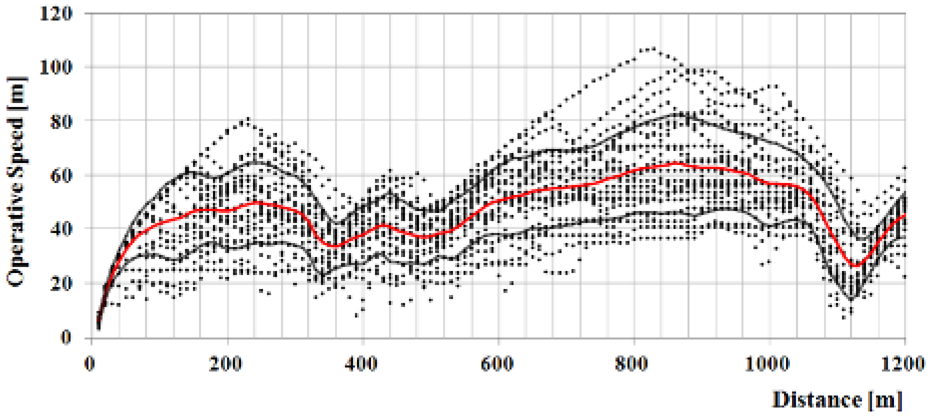

Figure 3. Speed vs Distance. Test under optimum visual contrast.

Figure 4 shows operating speeds measured during the Test no. 2. Since users were warned of the reduction in visual contrast, it must be inferred that the reduction applied to the first 400 meters of road is due to the visual cue. As expected, the long stretch of straight road offers a wide choice of driving behaviors. This is a consequence of the free visual perspective that provides full control of the environment around infrastructure. In the Test no. 1, speed exceeds 50 km/h from the section at 580 m to the section at 1070 m; in the Test no. 2, the speed is exceeded from section 710 m to section 1020 m, so that a reduction of length with higher speed and a delay in the achievement of this speeds can be noticed.
Comparing the diagrams of the speed shown in Figure 3 (Test no. 1) and 4 (Test no. 2) it is clear that in the initial straight of the road the drivers' behavior is quite careful. The subsequent presence of curves and the reduction of the visual field does not prevent the overcoming of the speed limit. On average, the subjects exceed a 50 km/h speed for 192.9 m, while reducing the contrast between pavement and road markings the maximum 60 km/h speed is exceeded in 54.1 m only. From the perspective point of view, the central part of the route is perceived by the driver as a possible danger. Test no. 1, which allows a free speed, shows the highest values of velocity. However, in both cases, the stretches with curvilinear layout are covered at 50 km/h.

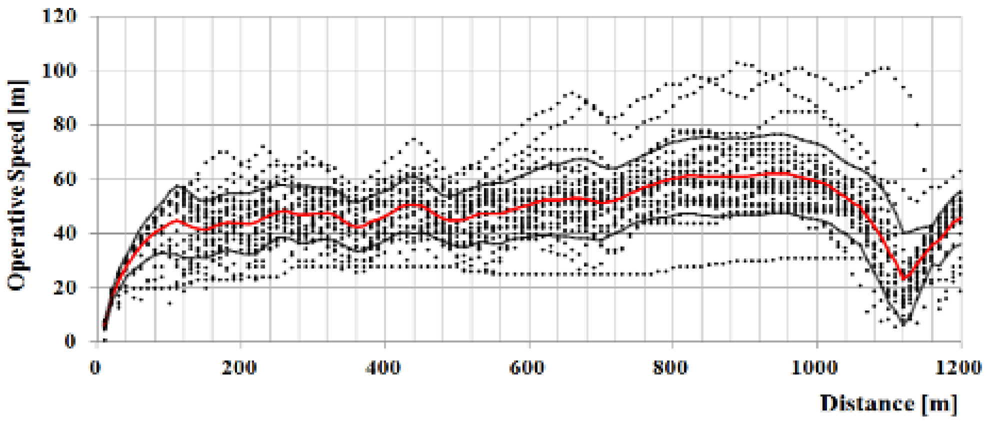

Figure 4. Speed vs Distance. Minimum contrast of color.

Table 2 (related to 10 km/h intervals of speed) puts in evidence the length of road where the speed limit is exceeded for both tests (mean distance and standard deviation are reported).
The results of Test no. 2 are only partially comparable with those of Test no. 1, where there is a high tendency to exceed the value of 50 km/h. Figure 5 clearly shows the relationship between the two experiments: the visual stimulus (minor contrast) has the effect of redistributing the velocities on lower values, especially in classes 30-40 and 40-50 km/h. Whenever the subject suffers the sign variation influence a spot difference in speed correlation will occur (Figure 5b). Table 2 shows that this trend also applies to the distances where the limits are exceeded.
The analysis of variance was conducted between the results obtained by the two tests and shows a significant variability in driver behavior. The response to visual stimuli in both tests is highly subjective.

Table 2. Length of the road where the speed limit is exceeded (mean distance MD and standard deviation ST; 1, 2 is the number of the Test).

Speed Range [km/h]	MD_1 [m]	MD_2 [m]	ST_1 [m]	ST_2 [m]
0-9.99	21.11	20.74	3.2	4.74
10-19.99	36.67	31.11	53.1	20.82
20-29.99	130.37	155.93	85.6	139.62
30-39.99	212.22	384.44	121.1	103.56
40-49.99	288.52	370.74	134.2	156.79
50-59.99	321.74	192.96	142.8	158.67
60-69.99	239.33	54.07	113.0	106.09
70-79.99	162.73	-	84.2	-
80-89.99	242.50	-	55.3	-

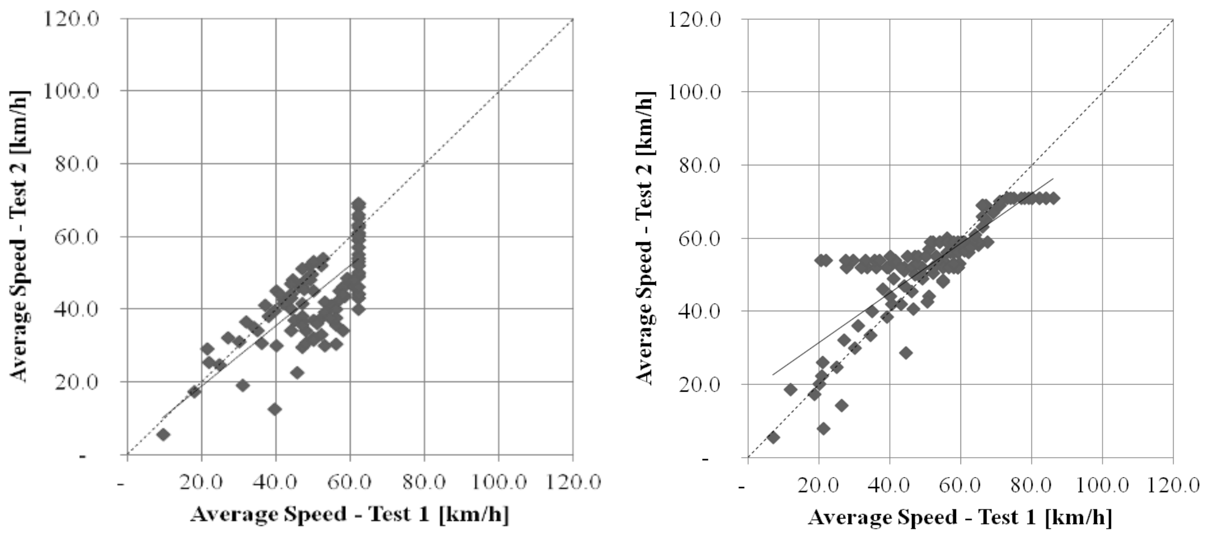

Figure 5. Comparison between the speed measured in the same road section, during Tests no. 1 and no. 2 when: (a) driver is not influenced by road signs; (b) driver is influenced by the light contrast simulated.

The F test conducted on individual subjects shows the lack of a dependence of the variances of speed (see Table 3). In 26 cases (96.26%) the diagrams of the speed distributions are comparable (R> 0.50), but a good correlation is reached in 3 cases only (11.11%, R> 0.90). Only 4 drivers (14.81%) in both tests respect the speed limit of 50 km/h. This is also in line with the trend observed during the research project (11.84%, over 100 Volunteers).

The infringement of the speed limit signaled by the vehicle (50 km/h) determines a reduction in the number of transgressors (4 to 8).

The test χ^2 compare the results of both the experiments. Table 3 shows the importance of visual stimuli related to speed limit (p <0,01).

Figure 6 puts in evidence the relevance in the choice of the sections analyzed. A global consideration of the subjects presents good correlation between the results from both the tests (R^2> 0,86 – Figure 6a). It should be noticed that the driving simulator allows to create a constraint for risky driving behavior; particularly, it is possible to focus on spotted section (Figure 6b), chosen along the “S-Shaped” curve. Here there is a greater dispersion of the results: this difference is less evident when considering the entire route. In the central section the greatest variation of the average driving speed can be observed, as well as the dispersion of results (Figure 6b). Moreover, the constraint allows to reduce in most cases also the distance travelled in risky conditions.

As it concerns all the subjects who faced both tests, 21 of them (77,78%) reduced the distance where the speed was higher than 50 km/h. 5 volunteers only (18,52%) have changed their driving behavior and presented speed values below 50 km/h. 3 drivers made worse the second test, against all expectations.

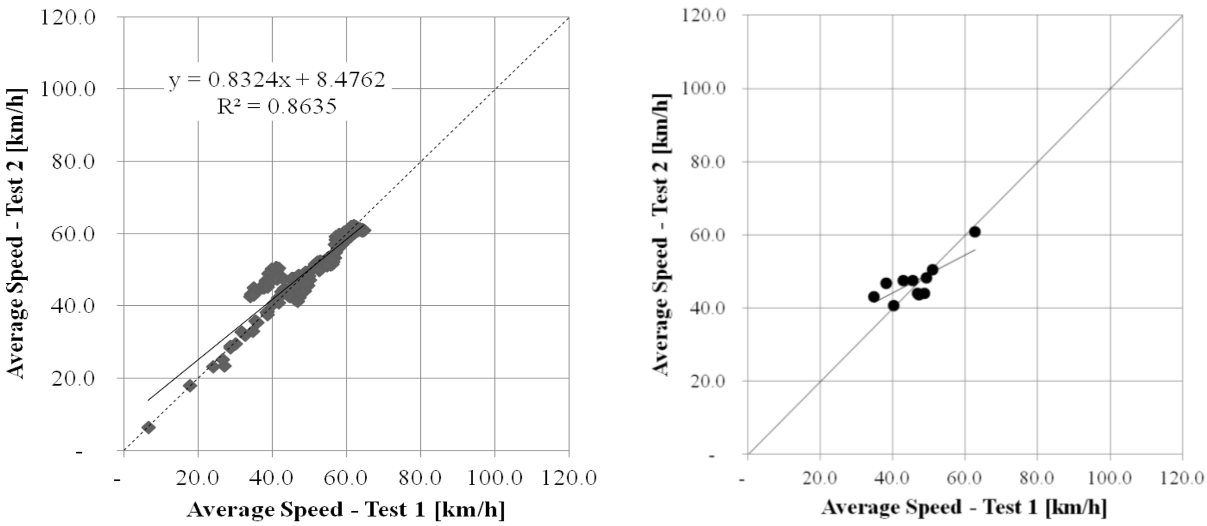

Figure 6. Speed Range Test no. 1 vs. Test no. 2; (a) Average Speed of all subject, (b) Average Speed of Spotted Sections.

Table 3. Statistic Test on speed distribution (p<0.01).

ID	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Test F	0.46	0.00	0.01	0.20	0.40	0.00	0.09	0.01	0.28
χ^2	12.30	14.99	8.89	12.76	7.96	20.64	13.95	14.52	9.77
R^2	0.86	0.85	0.89	0.83	0.79	0.80	0.75	0.85	0.85
ID	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Test F	0.00	0.10	0.00	0.00	0.15	0.00	0.00	0.11	0.00
$\chi2$	15,76	4,77	23.42	8.98	7.63	13.95	33.40	6.54	19.63
R^2	0.76	0.66	0.90	0.74	0.74	0.81	0.90	0.84	0.89
ID	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**
Test F	0.00	0.02	0.00	0.05	0.01	0.05	0.06	0.06	0.25
$\chi2$	6.69	6.10	3.27	12.77	13.23	6.75	9.69	9.71	6.03
R^2	0.72	0.79	0.36	0.80	0.94	0.71	0.88	0.88	0.84

4. CONCLUSION

The first conclusion of the research is that the driving behavior of those who undergo testing in a "full immersive" virtual environment is affected by interactions with the environment in which the simulation takes place. Stimuli both external (signs) and internal (running speed and signals related to speed overcoming) to the vehicle are well received.
However, external stimuli are usually neglected to the detriment of road safety: in fact, except for a few subjects, there is a lack of attention for the speed limit. Although the signals are mostly clear and designed accordingly to geometrical rules, they have a limited effect on driving. Vice versa, the subjects offer a natural attention to stimuli that represent variations inside the vehicle.
Moreover, the experiment has shown that the stimulus of the road marking contrast is more effective than expected. In particular, a specific test revealed that the environment variation doesn't prepare the driver to the safer behavior, thus the average operating speed tends to be lower. The results highlight that there are frantic reactions on the signs contrasting; even the diagrams that show the driving response undergo oscillations and localized adjustments. Road designers and safety managers must take this into account, in consideration of the fact that speed's sampling was carried out with intervals of 3 ms and thus there is a lack of bonding to reality (below the normal reaction time of subjects investigated).

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