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RESPONSE TIME TO HAZARD: THE ROLE OF ATTENTION, DECISION MAKING AND EMOTIONS ON EXPECTATIONS IN REAL-LIFE AND VIRTUAL DRIVING

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The Role of Attention, Decision Making And Emotions on Expectations in Real-Life And Virtual Driving

Overview: The human factor while driving

While driving, how long does it take for drivers to realize that a dangerous situation is unfolding? How long does it take to recognize the danger and realize that something must be done to avoid it? And in which way drivers develop a driving reaction: is it always the same or it could be affected by contextual and individual aspects? Could we learn to speed up and choose the proper reactions or are we bound to fixed mechanisms?

These could seem simple questions and tied to mere motor execution research field, but actually they imply a set of dynamics and psychological factors (the so called “human factor” in the road safety language) that make these questions an extremely complex research field, where the role of perception, attention, and decision making processes, activate a specific configuration while driving. These particular topics concerns an adaptive mechanism that protects drivers by road accidents, that can become highly automatic, that lead the drivers to optimize visual attention and working memory resources to be able to react readily to the most common road interactions. But, as in every cognitive economy process, sometimes an uncritical trust in these mechanisms can be dangerous and, if not properly monitored and controlled, lead to road accident. Distraction, superficiality, wrong interpretations of road crossing, wrong communication in the interaction with other drivers, misplaced risk perception, delay in realizing of a danger and delay in correcting the driving: when we speak about “human factor”, we are describing all these phenomena, that are reported to cause the 70% of deaths and the 80% of road accidents in our towns (OCED, 2006). In Italy there are every year 184.500 accidents with injuries, 3.650 deaths, and 260.500 wounded road users (ACI-Istat, 2009, 2010, 2011, and 2012).

New technologies exist to help and support perceptual limits that can warn the driver or even take over the control in case of dangerous situations. In the near future, we will have self driving cars in an automatic traffic environment. Devices like the *Collision Warning System* or the *Pedestrian Detection* will become common and off-the-rack on our vehicles. Nevertheless, even such

devices show some limit in their usage and in their functional typology: above all, they have to be integrated with the driver's human subjectivity, which will be mediated by the driver's attention and perceptual and emotional processes, to be actually functional (Lindgren, & Chen, 2007). Drivers should interact with such devices, becoming a supervisor, more than a driver, and they should be able to manage and monitor the road situation that the smart car is displaying (Birrell & Young, 2011): and its is well established that accidents most commonly occur when a person is forced to suddenly switch from automatic to controlled processing (Kay, 1971).
Also by this future trend the relationship among driver's expectations, confidence, action, situational awareness and the driving commitments will arise (Brookhuis, de Waard, & Janssen, 2001). When are we facing a real danger? When should we intervene ourselves or overlook the danger because the car has already detected the danger situation? Who is committed to take such decision? In which situation is preferable to intervene or delegate? What relationship there will be between the car's decision making processes and the driver/supervisor ones?
As we can see the situation, at a psychological level, become even more interesting, touching further elements such as intentionality attribution, delegation and meta-decision and decision making processes.

State of the art: Updating Reaction Times

So, how is the "human factor" composed and how can it be investigated?
Psychological literature has distinguished among five main components that are involved in the management of the driver's response in front of a potential hazard (Green, 2000; Summala, 2000): (1) orientation of attention in the visual field; (2) sensory and perceptual processing of environmental data (Groeger & Chapman, 1996; Crundall & Underwood, 1998); (3) appraisal and recognition of the potential hazardous stimulus (Lamble, Laasko, & Summala, 1999); (4) decision making and response selection (Green, 2000; Warshawsky-Livne & Shinar, 2002); (5) visual and motor coordination to execute the programmed

behavior. The emotional system acts as a human alert device in the monitoring process, and it could improve the detection of novel elements and the reaction to them (Damasio, 1994), but this system needs to be effectively coordinated in order to be useful for driving behaviors such as reaction times. (Underwood G., 2005). Expectations and available knowledge about hazard situations also can play an important role in the reaction times: experimental studies have shown that these elements can foster a more effective visual exploration and a faster motor response (Duncan, Nimmo-Smith & Brown 1992; Olson & Sivak, 1989; Martens, 2004; Koustanai, Boloix, Elslande, et al., 2008, Martin P., Audet T., et al., 2010).

Each of these components take part in the brake reaction time, that is the crucial amount of time that last between the appearance of a potential danger to the last moment where the crash could have been avoided by a reaction of the driver. Actually there is not a “single Reaction Time” (at singular) but there are Reaction Times (RTs). They are influenced by internal factors and external conditions that could speed up or slow down the entire response (Green, 2000; Isler & Starkey, 2010).

Yet, there is no agreement in the literature on which reaction times to adopt and in which situation. In the literature we find reaction time varying by a factor of 4, but according to which variables they change?

Even more ambiguity is found in the applicative domain, where different field of application, in different country utilize their own standard.

In Italy, for example, the reaction time has been considered, till 2001, to be 1 second, and, on closer view, this reaction time is based on the early studies on simple reaction time in the age of the first Italian industrialization and automobile diffusion in the 50’s. Since 2001 this value has been updated, taking into account a slight adjustment depending on the speed that sparks off criticisms (Benedetto, A. (2002) and that in the everyday life has always been considered of “about one second”: by day, by night, for young or older people, for emergency or foreseeable situations. In the rest of Europe reaction times vary from 2 seconds in Spain, Germany, France and Switzerland, while United

Kingdom's Highway Code and the Association of Chief Police Officers ACPO Code of Practice for Operational Use of Road Policing Enforcement Technology use 3 seconds for driver reaction time. In the majority of U.S.A., instead, the value adopted is 2.5 seconds.

Nevertheless reaction times are always considered as fixed and independent from the situation, although it has become common knowledge that for instance the use of cellular phones slows the total reaction time (Brookhuis, de Vries, & de Waard, 1991). These commonly used data, hence, do not point out clearly how psychological factors and individual variables can influence reaction times.

Real driving vs. Driving in Simulators: the importance of Research's Validity

There are not only theoretical variables that influence RTs, but also methodological factors as well.

The measurement modalities are not neutral aspect, or mere questions methodological relevance, but have direct implications on the created phenomena and on the triggered processes. The methodology used affects RTs as it affects the psychological processes that determine RTs. So it is important to understand and to quantify which aspect could be modified or influenced by the research contexts, in order to understand how laboratory data can have a strong external validity also in real-life driving.

Modern driving simulators have reached levels of realism, immersion, accuracy and driving dynamics that can give the driver a very accurate experience, and at the same time they can guarantee to the researcher a precise measurement of driving behaviors in different scenarios and solid internal validity to their data. They can provide and simulate situations that would be impossible to simulate sound and safely in real-life research, or replicated in everyday driving. Yet it could be questioned for RTs if the awareness of the driver and the protected contest of the driving simulator, could somehow still affect the reaction times emerging from these studies and their external validity.

In fact, the influence of emotion and expectations on the driver's performance raise several questions about the external validity and generalizations of results for the brake reaction-time, especially for experimental studies employing laboratory, virtual or controlled road settings where the danger or the potential risky situations are not actually perceived and felt like are n real situations (Lee, Cameron, & Lee, 2003; Kemeny & Panerai, 2003).

A systematic review of the different RTs in different methodological context has been already done thru the years, but there are few analyses that deepen the reasons of this influence on RTs. A systematical analysis on drivers' behavior in a real context as well as in different research contexts (laboratory, simulator) with different stimuli, could guarantee a more precise insight. In this way, not only it could be possible to study and describe the processes involved in RTs, in order to achieve a better road safety, but also to improve our knowledge about behaviors and learning transfer context, which could be virtual or real.

Operative side-effects for road safety

Hence, from an applied research point of view, the results of these research questions could improve the insight on the functioning of the psychological dimensions adapted to the driving task, also relating to new technologies and driving helper devices and virtual simulations (man-machine-road interaction). On the other hand, these questions have an extremely direct applicative value: for who produce such devices, to understand how persons interact, how they relate with these devices and which usage signification they have for the subjects. Also they can help road and infrastructure builder, to calculate how and with which times, drivers react according to the type of danger they face. In the same way the questions are interesting for who is involved in training (such as driving schools) as well for who produce and validate driver training course aimed to driving improvement, should be interested to understand how the processes bound to "human factor" behave in the different training simulations, and if they will be retained in an effective learning also in the real world. Insurance adjusters, as well as tribunals, are also interested to understand which type of fail or which automatisms have been involved, and if the driver's behavior could have been different to avoid the accident, using updated accurate and non-standard times and behaviors. Moreover, deep knowledge of these phenomena could be used by medical committees for driver license renewal, to understand which phenomena and processes are still usable to avoid ad accident, and to get enquiry tools that are validated externally, in real life context.

The Present Research

The aim of the present research is to face the aforementioned problems, through three main objectives (Figure 1):

I. Measuring how psychological processes bound to attention affect RTs, in processes related to decision making and emotional regulation interacting with drive expectations in a real context (Study 1);
II. Deepening how these processes modify the influence on RTs in a virtual simulation context and use RTs comparison to validate the test (Study 2);
III. Understand which elements of a virtual simulation could be used specifically for research and accident prevention, and how these could be exported to a real context, from a point of view of external validation of the driving reactions in danger situations (Study 3).

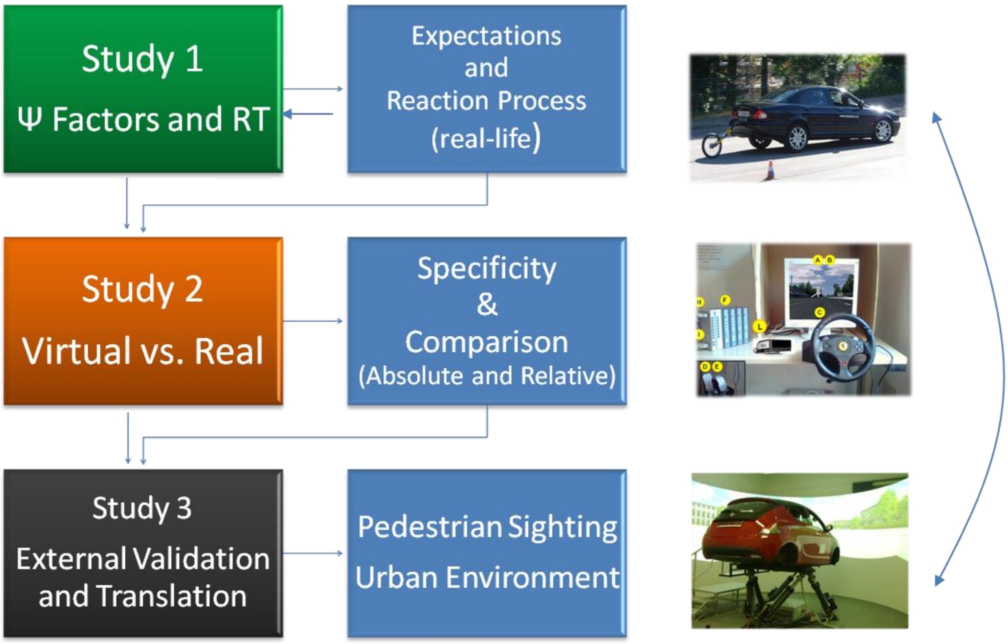


Figure 1. Study Articulation

A set of specific tasks will be created and expectations, urgency and the meaning of different RTs situations will be manipulated, in real-life vs. different levels of virtual simulations. Measure will be taken of whether and to what extent RTs vary according to different psychological process set up by the different driving conditions and tasks created by the different methodological operationalizations. Monitoring and recording the driver's behaviors in terms of attention and movement and pressure on the brakes, non verbal and physiological parameters of drivers to a similar task, will be crucial to provide a metric not only in terms of response times, but also for the psychological process that characterize different levels of realism and situational awareness.

Chapter 1

Brake Reaction Times
Theory and Implications

1.1. What Do We Know About Reaction Times?

What is Reaction Time

How long does it take for drivers to react to danger? When is the last period of time useful to take a decision and avoid the accident?

These questions are more complex then what they seem, as they allow us to point out different aspects of the human working modality while driving.

The focus of the different experts that analyze the process and dynamics of rod accident, is set on the few seconds that anticipate the crash. This lag of time is called brake reaction time and consists of all the actions, situations, environmental variables that may have determined and influenced the behaviors of the drivers and the traffic environment, that have lead to the car crash in that particular situation.

Reaction time (RT) is a parameter of driving behavior that has concrete implications in civil engineering to determine road design, in accident reconstruction to determine whether a crash could be avoided, as well as for applied psychology for studying psychological factors that define the role of human factor in determine road accidents, and in medical commissions to set fitness to drive.

Why they are Obsolete

Despite this importance there is no uniformity on the features and duration of the brake reaction times. There is no single value for brake RT, nor there is a shared view on the elements that are able to impact and influence the brake RT while driving.

In an analytic review on brake reaction time Green reported that braking time estimated in previous literature differed by a factor of almost 4 (Green, 2000). In Italy the brake reaction time was considered “one second”, based on laboratory studies on simple RT by Father Agostino Gemelli, that in 1951 was asked to study the RT for the upcoming industrialization and diffusion of the car in Italy.

That value is still used, with a slight adjustment depending on the cruise speed, to determine crash responsibilities, has entered manuals of accident reconstructions and used in prevention training, in spite of the more recent researchers and update that seriously questions such use of the brake reaction times.

Moreover in the last years an increasingly complexity and evolution of technology created a new generation of cars and safety device, as well as with the increasingly evolution of the traffic situations and car design, created a completely new driving context, that the modern driver has to face.

Cars of the future will be all equipped with intelligent supporting devices that will change the man-car relationship. Cars will be able to drive alone in place of the driver, that will be turned into a “supervisor” that will have to take the control only in critical situations more than actually drive. (Creaser, Rakauskas, Ward, Laberge, & Donath, 2007; Vlassenroot, Molin, Kavadias, Marchau, Brookhuis & Witlox, 2011). There already are off-the-rack devices that warn the driver when he is misjudging the situation (i.e. speeding, not braking while approaching a danger, line departing) and advanced driving automatic systems (ADAS) that take the control of the braking system pre-warming the brakes when the device detect a distance with the vehicle ahead decreasing too fast while the driver has not yet press the brake, and even activate a full braking autonomously if the danger is too near from the car ahead and the driver has performed no reaction on the brake (Bertozzi, Broggi, Coati, Fedriga, 2013; Broggi, Cerri, & Jung, 2009).

There are already technologies inside the roadway that can advise the car and the driver they are approaching a pedestrian too fast, and eventually stop the car, or intelligent device that can reduce speeding (Molin, & Brookhuis, 2007) (Figure 2).

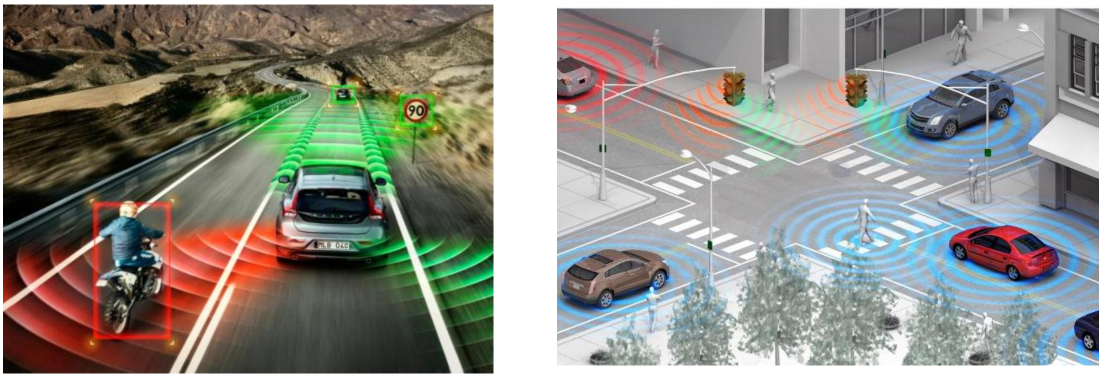


Figure 2. Advanced Driving Automatic Systems (ADAS) represent the present and the future for road safety. But ADAS Acceptance by the driver remain still a key factor.

These automatic devices seems to bypass every interest in RT as the car alone will be in charge of the reaction and the influence of the human factors and its flaws will determine road accident no more. But this is not the case. In fact these devices present several use limitations, can respond only to certain kind of potential dangers, at certain speed or in certain context and are not totally independent from the driver as are not able to recognize all dangers in the road (Beggiato & Krems, 2013). Moreover the complexity of the traffic system, the idiosyncrasy and unexpected events and interaction with other humans intention, is not -at present- delegable to advanced devices.

Therefore driver have to supervise and decide when is appropriate to take the control, they have to monitor the warning of the device and decide what is the best for this specific situation and they have to be ready to handle the situation when the driver is not working or it is unable to intervene. The device limitations and new feature require a different conception of the RT then. Is not only motor reaction to the appearance of stimuli, rather an interaction with trust, expectations, knowledge, urgency, attention and decision making (Huth & Gelau, 2013).

RTs are all dependent from these variables. Without an in depth knowledge of the RT in this new field there is potentially the risk that the interaction with these device, if not neither fully accepted nor fully understood, could actually create new potential critical driving issue, bounded with delegation, trust, acceptance and potentially dysfunctional RT.

That is why it is important to understand which psychological factors interact with RT while driving (with and without ADAS), how they impact on RT and under what condition.

Updating Reaction Times and Models

Scientific research has made relevant improvements in studying the interaction man-machine and more specifically the interaction human-car and driving environment, as well as the field of study about human perception, cognition and elaboration of motor responses in the neuropsychological and psychological field (van der Burg, Talsma, Olivers, Hickey & Theeuwes, 2011). These improvements point out that there are several limitations in the generalization for driving of standard and almost classic studies on RT. For instance classic RT test were based on simple reaction to single stimuli, using only upper limbs (Drury, 1975; Hoffman 1995) of subject in front of a monitor in laboratory setting (Isler, Starkey, 2010), that present several limitations in external validity when generalized to real life driving.

So what do we know about reaction times while driving now? It is possible to find at least two types of research fields in literature: road and traffic engineering literature that consider the RT as part of the modeling of process activated by the driver to avoid the accident, and traffic psychology literature where RT are used as measure to study the salient elements that affect response.

1.2. RT in Road and Traffic Engineering

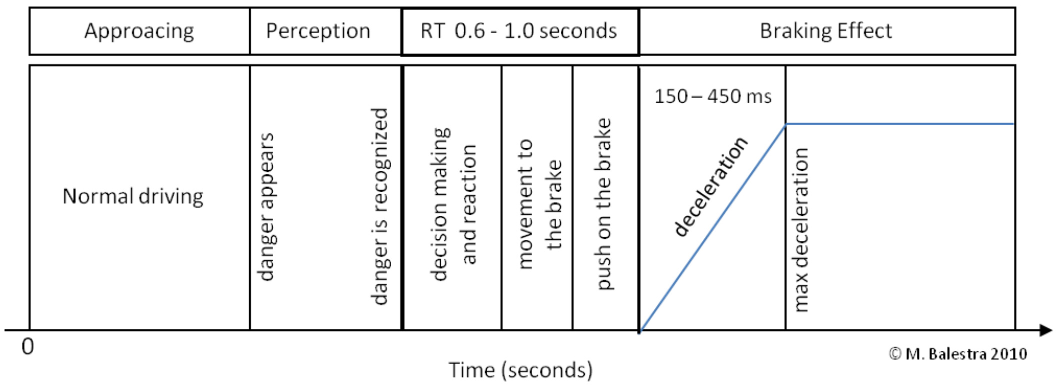
Time, Speed and Space.

For road and traffic engineering reaction time is defined as the time between the first driver's perception of the stimuli and the moment in which the vehicle changes its driving condition (Burg & Rau 1981), that is a change in the speed or trajectory, as the consequence of driver's reaction (Törnros, 1995). RT adopted to determine design of road regulation, are different in different part of the world: RT is 2 seconds for Switzerland, German, France, Spain. 1 second for Italy, corrected in 2001 as RT = (2.8 - 0.01V) where V is speed in Km/2. RT are considered fixed by the lawmaker, as a constant in the equation for calculate the distance needed to stop a vehicle (D_{stop}), as a function of distance travelled during the reaction (D_1) + distance travelled while the brake are pressed (D_2) as follow:

$$D_{stop} = D_1 + D_2 = \frac{V_0}{3.6} RT - \frac{1}{3.6^2} \int_{V_0}^{0} \frac{V}{g\left[f_{\max}(V) \pm \frac{i}{100} \right] + \frac{Ra(V)}{m} + r_0(V)} dV$$

where V_0 is the initial speed of the vehicle [km/h], f_{max} the maximum value of longitudinal friction, i the longitudinal slope [%], $Ra(V)$ the aerodynamic resistance [N]; $r_0(V)$ the friction resistance [N/kg], m is the mass of vehicle [kg] and g is the gravity acceleration [m/s2] (A. Benedetto, M.R. De Blasiis, C. Benedetto, 2002).

The German manual for accident reconstruction by Burg & Rau, 1981 instead, consider RT (Realtiondauer) as an interval of seconds that starts when danger is recognized (*Gefahr wird erkannt*) and ends with the beginning of the braking pressure (Figure 3). RT is not a constant value as it lasts between 0.6 and 1.0 seconds, and it has minimum and maximum values for three specific phases. However this kind of definition presents several theoretical and methodological issues: RTs are seen as a sequence with hierarchical steps (first perception, then decision, then movement),



1. Eintscheidungszeit und motorisce Reaktion (Decision making and reaction)	*435 – 770 ms*
2. Umsetzen (Movement)	*150 – 200 ms*
3. Bremsbeginn (Brake pressure)	*15 – 30 ms*
Total RT	*600 – 1000 ms*

Figure 3. Model for Reaction Times built in 2010 based on Burg & Rau, 1981 RTs

while modern psychological and neuropsychological models describe perception, action and decision making as a process, with several emotive and cognitive functions unfolding together (Seya, & Watanabe, 2012; Yotsumoto, & Watanabe, 2008). Moreover it is difficult to determine when and how the driver has recognized the danger, and this model does not explain the reason for the variation of gap of time nor explain what are the variables that may create that lag in the RT. Different research have discussed the fact that there may be other variables other then the speed of travelling that impact RT (Lenné, Triggs & Redman 1997) arriving to the conclusion that: there is an impact of the nature of the stimulus to activate different "*cognitive and decision action routine*" (Adam et al., 1996), that different frameworks and setting affect perception and reaction mechanisms (Michaels, 1993; Proctor, Van Zandt, Lu and Weeks, 1993), that RT should be assumed different for urgency, expectations and as function of learning and mental workload of the driver (A. Benedetto, M.R. De Blasiis, C. Benedetto, 2002). All variables that are proper of the scientific field of Psychology.

1.3. RT in Psychology and Traffic Psychology.

The Human Factor for Reaction Times

Since the origin of scientific psychology, at Wundt's laboratory for experimental psychology in 1879, RT were investigated as a specific area of interest of physiology, as well as used as an indirect measure of the cognitive process for specific performance in experimental settings (Kosinski, & Cummings, 2004).

Psychologist and Physiologist have measured the difference of RT as function of *simple vs. recognition vs. choice experiment* (Donders, 1869; O'Shea & Bashore, 2012), assessed the differences of RT to *audio vs. visual* stimuli (Galton, 1899; Saville et al., 2012) and the influence of *duration and intensity* of the signals (Froeberg, 1907; Hsieh, Lin, & Chen, 2007). Study on attention and attentional process showed that RT are influenced by the *saliency* of the stimuli for the subjects, and interactions between *reinforcement* and bottom-up stimulus signals (Sasaki, Nanez, & Watanabe, 2010; Shibata et al., 2011); *novelty* of the stimuli can influence of the response and *perceptual learning* process that occurs during the test (Seitz & Watanabe, 2005) Even irrelevant stimuli influence the RT (Tsushima et al., 2008) and in particular *selective attention* is achieved via a competition process that see the *executive automated system vs. voluntary orienting system*. Depending on the motivation and type of situation, the working memory can activate or deactivate different areas of the Dorsolateral Prefrontal Cortex (LPFC) to analyze and select the correct response (Seitz, Kim & Watanabe, 2009), and the effort requested in visual attention is reflected in RT and can be measured by N2pc component of event related brain potential to evaluate judgment (Monika Kiss, Brian A. Goolsby, Jane E. Raymond, Kimron L. Shapiro, Laetitia Silvert, Anna C. Nobre, Nickolaos Fragopanagos, John G. Taylor, and Martin Eimer, 2007).

RT were also found dependent on the level of physiological activation, *arousal* (Welford, 1980), and muscular tension and pre activation of the brain by muscles' *isometric contraction* (Entrye & Kinnugasa, 2002). *Cognitive load* is another impacting factor on RT by drawing cognitive resources for instance cellular phone use increased RTs (Brookhuis, de Vries & de Waard, 1991), in the same way that in-car stimuli slow the driver response, reducing drivers' resources (Summala et al., 1998).

Age can also influence simple and complex reaction times (Luchies et al. 2002; Riddervolt et al., 2008). Basic RT studies generally find a slowing with increased age (e.g., Welford, 1977), but not always RTs get slower with age (Der & Deary, 2006) there are other factors that covariate with age such as *experience* in recognize stimuli, carefulness selective attention, *fatigue* (Botwin & Thompson, 1966; Redfern et al., 2002; Whiting et al., 2013) that create a counterintuitive co-variation in RT that mediate age effect. In particular RTs while driving have produced mixed results, with older drivers slower in some cases (Broen & Chiang, 1996; Greenshields, 1936; Lings, 1991; Martin P.-L. , Audet, Corriveau, Hamel, D'Amours, & Smeesters, 2010) and not in other studies (Korteling, 1990; Lerner, 1994; Olson & Sivak, 1986; Wright & Shephard, 1978).

Gender was found to be faster for males then females (Noble, Baker, & Jones, 1964; Dane & Erzurumlugoglu, 2003), also in driving context (Lings, 1991; Wright & Shephard, 1978). But, interesting enough this trend is changing as more woman are participating in activity before precluded to women such as driving and in fast-action sports that can actually improve RT (Silverman, 2006).

To these psychological factors, traffic psychology added a specific set of variable specific for driving that should be considered when studying RT. In fact RT while driving require specific visual-audio-tactile attentional process and decision making conditions that lead to complex actions in interaction with a car, that influence RT especially when facing dangerous and critical situations. In this kind of research three main psychological factors are pointed out, along with specific working modalities that influence RT specifically while driving: expectations, urgency and type of stimuli (Chapman & Groeger, 1996; Chapman & Underwood, 1998; De Waard D., Hernández-Gress N., & Brookhuis K.A. 2001; Lamble, Kauranen, Laasko, & Summala, 1999, Summala H., 2000).

Expectancy: Experience, Learning and Sequence effect.

In another meta-analysis of brake response time studies Green (2000) found that expectations was the variable that was able to explain the most part of the variance of RT variability. When the driver is alerted and is expecting a signal to immediately appear total RTs vary from 700 - 750 ms. But when the driver is facing *completely unexpected* events total RTs vary to more than 1500 ms. Not only temporal expectations can be manipulated, but also spatial expectations (the directions from the stimuli comes) and type of stimuli expectations (i.e. Braking signals). Experiment recording RT to expected stimuli are important to understand the "boundary condition" of RT (Green, 200) and can be used to understand the response to regular and recurring stimuli in everyday life, such as a traffic light lights. Drivers know the stimuli and know the appropriate response to this situation, applying the correct script (e.g. Abelson, 1981; Anderson, 1983; Garling, Fujii, & Boe, 2001; Neal, Wood, & Quinn, 2006) as learned with driving experience. However in the driving conditions were no recurring stimuli or surprise events happens, RTs are significantly slower as the driver have not sufficient *driving experience* to develop an automatic response to these surprise or low probability events. Sometimes even no response in time to avoid collision can be found.

In these kinds of researches the selection of the surprise event is crucial as it must be not deductable from the context and somehow be still pertinent to driving context. Moreover the surprise event can be provided for only one trial, and not in sequence events. In fact as expectancy increases with *exposure*, driver can respond faster throughout the experimental task to similar stimuli with a reduction of RT of 374-433 ms (Engström, Aust & Viström, 2010; Lee, McGehee, Brown, & Reyes, 2002).

This learning effect can also have to do with the fact that repeated measure can tune in the drivers' working memory and giving a priming effect with recurring forward feedbacks, so that attention will be better focused on expected features of the road scene (e.g. the place where the stimuli will appear, the sound of a delegating car) and a motor reaction will be anticipated (Dingus et al., 2006).

As pointed out by Aust, Engström and Viströmin in 2013, it has been very common for RTs studies to set up experimental task that expose subjects to repeated critical events, calculating then the average response (Abe & Richardson, 2004, 2005, 2006a, 2006b; Cheng, Hashimoto, & Suetomi, 2002; Jamson, Lai, & Carsten, 2008; Kramer, Cassavaugh, Horrey, Becic, & Mayhugh, 2007; Scott & Gray, 2008). With a few exceptions, the researchers collected data for many trials on each driver and participants have become practiced (Lings, 1991).

This use of repeated events can create expectations that undermine external validity of critical events, limiting generalization to real-life braking events in dangerous situations, rising critical concerns about the methodological use of paradigms that do not include expectations uncertainty in the drivers (Dingus et al., 2006). It is however hard to evaluate critical events such complete surprise events, as even in real life situations the emergencies are not completely or potentially unexpected *in toto* by the driver, rather it is the event's contingency in the driving scene as perceived by the driver.

Moreover without repeated measure it would be difficult to reach some internal validity conclusions, but even with random event timing and trials to mask an event, it is impossible to avoid any expectancy in the driver at all. This is why that at least expectancy should be carefully monitored and manipulated by the researchers, with a precise attention in test design to expectancy and on-line or follow up system that is able to give information about the driver's subjective experience of the test, to better control what, when and how the levels of driver's expectations about the test were unfolding during the specific task (Dingus, Klauer, Neale, Petersen, Lee, Sudweeks, et al. 2006).

Speed: Time to Collision and Urgency.

As Road and Traffic Engineering point out speed of travel is found to impact RT: for instance following the Italian formula for calculating RT the predicted difference between reaction times at 110 km/h and 70 km/h would be 400 ms, but that is 20 times greater than what is commonly accepted in literature (A. Benedetto, M.R. De Blasiis, C. Benedetto, 2002) and no explanation on the reason behind this influence is clearly given.

To better explain the influence of speed two other factors may be introduce: *Time to collision* and *Urgency*. Starting from a meta-analysis on the influence of working memory on braking events, Engström found a linear correlation between RT and initial time headway of the brake signal on the lead vehicle, that is: the slower headway time when the signal appeared, the faster the RT (Engström, 2010). This is because the initial time headway of the brake signal determine the time for the driver to become aware that there is sufficiently strong looming cues to start a response reaction. This time is also inversely correlated to time-to-collision (TTC) available for the driver. Time-to-collision is the ratio between the optical angle subtended by the lead vehicle and its expansion rate, a quantity known as tau (Lee, 1976), but since the studies of Fechner and Webber, this variable if found as dependent on the subjectivity driver and thus it can impact RT. In addition TTC is strongly correlated with the sense of *urgency* created by the stimuli, in order to avoid an incoming crash (Summala, 200). As found in classic psychology studies a greater sense of urgency should lead to faster RT because of greater arousal activation (Yerkes & Dodson, 1908). However not always a shorter TTC always means greater urgency. Result of traffic research suggest instead that RT vary as a U shaped function, that decrease only inside a short range of time, and then becoming to increase when the TTC is too short (Welford, 1980). Manipulating TTC is possible to obtain shorter total RT even with speed increasing from 40 Km/h to 60 Km/h, but with no psychological effect for further increase up to 80 Km/h (Chang et al., 1985). When the TCC is too long sometimes there is no need to respond promptly with fast RT or with a full break response. In two different and independent studies Summala and Koivisto (1990) and Hankey (1996) found a slow RT of 1700 - 18000 ms with a TTC of 3 seconds. Sometimes the urgency is not so immediate for the driver, that no response on the brake is given at all, but rather and avoidance maneuver on the steering wheel is obtained, and RT for steering are about 300ms faster than the time it takes to move the foot from accelerator to the brake pedal (Hankey, 1996). This may have little to do with TTC and urgency, rather than on perception and decision making process (expectancy).

The relevant range of criticality for one stimulus should be considered in RT studies as well monitoring the response on all the phases of the brake process, for showing the developing different type of response as function of urgency, TTC and expectancy.

Braking Signals: Positioning, Movement and Type of stimuli.

While driving the driver has to react to specific exogenous stimuli, but Some hazards are more attractive than others (Crundall, Chapman, Trawley, Collins, van Loon, Andrews, & Underwood, 2012). The most used stimuli used to study RT while driving is a leading vehicle ahead of the car of the driver, that suddenly starts breaking maneuver, in a pre-crash test. Many experimental studies use leading vehicles (e.g. Summala, Lamble & Laakso, 1998) with and without the rear brake of the car working, while other use just a braking red light that simulate the rear brake of the car without an actual car, or use forward collision warning (FCW) systems when simulated critical driving situations unfold (Aust, Fagerlind, & Sagberg 2012).

Another types of stimuli are obstacles moving or appearing in front of the vehicle. Usually is another car, or a moving object (Olson & Sivack, 1986).

Few researches use only auditory signals (i.e. the noise of a brake, or a crash), but audio is often integrated with the visual stimuli (i.e. FCW audio signals or the noise of the tires with the ABS working during an emergency brake). All this different signals produced different RT (Green, 2000; Horswill &

McKenna, 2004; Sagberg & Bjørnskau, 2006) so it would be interesting to not use just one type of braking signal.

Moreover RT to stimuli that can be foveally viewed are faster than stimuli that appear on the visual periphery, that is why looking at stimuli inside the car reduce the visual field, forcing an accommodation to near distance and outside objects to be perceived by peripheral view, slowing the RT for external objects (Velichkovsky, Rothert, Kopf & Dornh, 2002). While driving stimuli change often their position, from foveally to peripheral view, and often target objects move in and from the side of the road to straight ahead view, changing their saliency and their speed. Movement is a factor in grabbing driver's attention faster (Green, 1983) as sometimes a stationary target could be more relevant and thus fostering a more rapid response. That is why a threshold for static / moving stimuli to become recognizes as a danger should be investigated as part of RT while driving.

Another particular driving factor that can impact RT is the type of route selected for the test. Following turns in a road that present different curve degree, requires more attention and demand more resources than simply steering a straight road. The more articulate the route for the experimental test, the slower the RT (Alm and Nilsson 1994; Korteling, 1990), that is why response to the stimuli should take into account the placement and position in the route (turn, straight-away) when measuring RT.

1.4. So how long does it take?

This quick review seems to show a renewed sensibility in methodology that regard the design of experimental studies that aims to evaluate RTs. There are specific features in RT research that underline the influence of the concrete methodological choices that impact the psychological process of the driver when facing RT to danger. And as these processes determine directly and indirectly the response time process, modifying directly the outcome of the measures of RT.

As Green debate at the end of his meta-analysis:

> *"There is no single "best-guess" value for brake RT. However, there is sufficient convergence among studies […] to demonstrate that expectancy has the greatest effect of all (Green, 2000).*

When investigating risk perception, expectations can influence urgency, attention, and response process in dangerous situations. The methodology use to replicate or study dangerous situations is not neutral regarding the expectations created and then the response measured. The psychological effect of choosing a methodological operationalization of variables should be carefully considered when investigating RTs in particular.

The aim of the present research becomes now not just the investigation of RTs thru considering systematically the influence of the main psychological factors (urgency and expectancy) in determine attention, emotion and decision making process in facing danger while driving, but also how those process are influence by the methodological context of the research, and how modified the RTs.

What is the specific influence of a context? Can data be translated from one to another? Can a validation of a methodological pattern be underlined through different research context and methodological choices?

Answering these questions could be interesting to understand not only how long does it take to recognize a stimuli, evaluate the relevance with the situation, decide what motor reaction is appropriate to the dangerous situations; but also better understand the influence of mental models that determine expectations, and how they influence the responding process and the on line monitoring of the feedbacks of the actions facing danger while driving. Analyzing these factors in different context could better shed light on the process, using RT also as a measure of the process that unfold during the dangerous situations, in those crucial seconds that could prevent road accident.

This kind of research open the possibilities not only to reconstructing road accident including psychological factors in RT such as expectancy, but also for evaluation of different test and training in order to contextualize the methodological choices to real life phenomena and better understand the process in the drivers' "black box".

In the light of the foregoing, we now move to more methodological review about the way RTs can be measured, going towards a comparison of the two most common research setting: real-life driving and virtual driving.

Chapter 2
Measuring the RTs

Psychological Factors as Function of the Methodological Operationalization

2.1. How To Measure RTs

The study of RTs while driving is not independent from the psychological processes that intervene when facing the dangerous situations while driving.

Settling our analysis on this field of research, and in particular on the influence of expectations, emotions, attentional and decision making process that regulate the risky situations in the response times, the methodology used become then a crucial issue.

In fact, as is in all Psychological experimental research, there is always an influence of the context, of the task, the instruments, the expectations and of the overall methodological paradigm used for the research's objectives. Different configurations of the settings and of the stimuli could actually activate different process and factors that would lead to different reaction times and results.

The comparison of the methodological factors that influence this change in RTS is the second main objective of this analysis. Our aim is to understand what aspects of visual attention, emotional and decisional making process in brake reaction task are influenced by the methodological variables, and what process are, instead, constant thru the different methodological options.

In particular, two macro methodological variables are considered here for the methodological operationalization: the *setting* and the *measuring paradigm*.

Under *setting* we consider all the debate about the use of driving simulators and real-life driving: this debate includes the stimuli, the task, the equipment, the tracks, and implies issue on perception, expectations, motion and risk perception.

Under *Measuring Paradigm* we consider the theoretical and methodological choices to measure the driver response. That is to say the conceptualization and operationalization of the variables in specific equipment, the index and the variables selected, the phases of the reaction analyzed and the sample and the target population.

This kind of objectives are particular interesting not only for research purposes in RTs, that is to better understand how the psychological factors influence driver response in different driving situations, but also to better understand the specific features of methodological operationalizations on the drivers' expectations and attitudes in RTs situations. This investigation could provide interesting data for the hefty debate on external validity of simulations and training used in research and in prevention for road safety. Starting from a valuation of differences and similarities of an identical process triggered by the same phenomena but for two different contexts (e.g. virtual vs. real-life driving), it could be provided specific insight for internal and external validity for the generalization of more accurate and update RTs data obtained in different driving simulations.

2.2. Real-life Driving vs. Virtual Driving

The debate about the relationship between real vs. virtual settings is well analyzed and studied in many field of Psychology, going from methodological to theoretical implications on research and its implications on perception, attitude embodied cognitions and behaviors (Carberry & De Rosis, 2008; Knoblich & Flach, 2003; Lakoff & Nunez, 2000).

In terms of validity (internal and external) many studies have investigated the relation of perception, emotions and cognitions in real and virtual setting, to point out when and under what conditions a phenomena can be studied in virtual world, and to better understand the specific features and limitations for exporting results from virtual world to real world phenomena (Anderson, & Swing, 2009; Bailey, West, & Anderson, 2010; Barlett, Gorini, Gaggioli, & Riva, 2007; Juul, 2011; Klasen, Weber, Kircher, Mathiak, & Mathiak, 2012; Zlatev, Racine, Sinha, & Itkonen, 2008).

Also for Traffic and Transportation Psychology the debate about how to study phenomena and how to translate knowledge from real and virtual task is a relevant issue (e.g. Allen, Park, Cook & Fiorentino, 2007; Bella, 2005; Ciceri & Ruscio, 2014; Godley, Triggs & Fildes, 2002; Mitgutsch, Rosenstingl, & Wimmer, 2012; Underwood, Crundall, & Chapman, 2011). This is not just a matter of methodology, but the research setting has implications on the actual phenomena measured that is re-created in a simulation (virtual or real) with some specific features that are able to impact the result that can be obtained, so the external validity is a crucial issue to better understand the driving phenomena, and RT in particular.

In literature can be found three main experimental contexts in which research on RT is made: Equipped car in real-life driving, virtual simulations and naturalistic observations.

1) Virtual Simulations

On his review on Reaction times, Green in 2000, commented about simulator studies:

> "*Compared to the roadway, simulators present simplified visuals, loss of small texture cues, smaller field of view, no depth from stereopsis, and so forth. There are usually no nonvisual cues, which may play an important role in motion perception. There are fewer distractions, cognitive load is small, and the driver likely makes fewer eye movements to investigate objects in the peripheral field. There is no rearview mirror to check. McGehee, Mazzae, and Bladwin (2000) attempted a direct comparison and concluded that simulators produce brake RTs that are 0.3 sec faster. However, they found steering times similar.*"

Now, in 2013, Off-road studies of RTs are the most common and spread studies in transportation psychology. Big improvements in the field of virtual simulator studies have obviously been done: the visual representation is way more reach and accurate, with more texture cues, with audio and vibrotactile cues with moving mock-ups and rearview mirrors. In the last years several researches have proved that driving simulators studies can be a valid alternative to real-life driving studies: they are more efficient, overall less expensive, more safer and could provide a more controlled data collection. It is possible to outline three categories:

I. test that record driver's response to visual stimuli (such as videos) in a lab setting, in front of a wide field of view desktop system with three or single monitor display (e.g. Underwood, Crundall & Chapman, 2011)
II. test conducted inside car mock-up or an equipped cabin with wide angle projected display (e.g. G. Weller, 2010)
III. tests that record response time inside the interactive virtual scenario created by driving simulators of different types (e.g. Chan, et al. 2010)

Training results have been published previously that show some differences in performance between simulator configurations (Allen, Park, Cook & Fiorentino, 2007).

Figure 4. Three different types of driving simulators, with completely different working modality that could impact on the driving responses of the drivers.

Moreover there are plenty driving engine that create virtual scenarios that can be projected in front of the driver, as well as different levels of automatized platform that could recreate the movement of the car, according to different levels of motion realism (Figure 4). It is possible to evocate different scenarios, simulate and conjure up almost every critical driving situations, even the ones that would have been difficult to replicate and coordinate in real-life driving (Slob, 2008).

However.

Even with high levels of immersion or during flow experiences, the situational awareness of being in a driving simulator and driving in a fictional road is present. It is not clear how and at what extent this situational awareness impact on RTs, but research had reported an interaction effect on expectations, visual perception and in particular danger perception, sense of urgency and ludic simulation (e.g. Breuer, J., & Bente, G. 2010) that have a potential interaction with the variables that impact RTs.

Drivers are aware that virtual driving will not have any consequence on their driving behavior, and will act in a different way than in real-life driving (Lenné, Groeger, & Triggs, 2011). Moreover as all virtual extension of spatial abilities, driving in simulators require an adaptation process, as movement and procedure learned in real-life driving must be re-adapted and re-adjusted to the virtual physical law of the simulated world. Criticalities come from the field of perception, and involve motion and target localization and motor executions of actions in 2D / 3D virtual reality (Takahashi, Meilinger, Watanabe, & Bülthoff, 2013). Experienced drivers can find difficult to drive a virtual car, and vice versa, inexperienced or novice drivers can find no difficulties at all when driving virtual simulations (Weiss, Petzoldt, Bannert, & Krems, 2013).

The use of driving simulators introduces, in addition, another specific critical factor, that is simulator sickness (Brooks, Goodenough, Crisler, Klein, Alley, Koon, Wills, R. F. 2010). Like motion sickness, simulator sickness is considered a syndrome, for the span of its symptoms that include headache, sweating, drowsiness, disorientation, vertigo, nausea and dizziness (Ebenholtz, 2001; Kennedy et al., 1993; Cobb et al., 1999) and more specifically negative effect on psychomotor control. It is considered able to vary its effects in interactions whit gender, mental ability and virtual-driving experience of the driver and with older adults more susceptible to its effect than younger participants (Roenker et al., 2003) especially for eye movement disturbances (Brooks et al. 2010). Simulator sickness is also dependent on exposure time (Cobb et al., 1999) with a steady increase during time, and with a drop-off from the experimental test of 15 minutes for drivers who are experiencing high levels of simulator sickness .

For all these reasons it is clear that simulator sickness can potentially confound data (Lerman et al., 1993; Cobb et al., 1999), limit the effectiveness of training (Hettinger et al., 1990), and influence participant dropout rates (Cobb et al., 1999).

Equipped car in real-life driving

Research is carried out using an equipped car in a controlled track, or in a safe area or in partially closed real road. The driving experience for perception, and visual and tactile feedback have strong external validity, and the potentially consequences and responsibility of unsafe driving, even in a safe setting, are in theory real (Li, Jain, & Busso, 2012).

RT research using equipped car in real-life driving have more ecological validity then driving simulators, and could replicate some driving phenomena for reaction test in the same way as they would appear in reality: the brake of a leading vehicle, a red traffic light. However they could not replicate all the different scenarios that a normal driver can face in everyday driving conditions: for instance there are a whole range of stimuli that cannot be replicated in real-life driving for obvious safety reason, such as dangerous pedestrian crossing, driving violations and inevitable crashes.

Moreover the driver, even in blind or double blind design experiment, is usually aware that is part of an experiment and the researcher or some part of the equipment is present on board. So they are generically more alerted then normal driving conditions, and that could yet affect the driving response.

Naturalistic observation

Is the most ecological situation, but on the other hand it lacks of control and internal validity. Recording equipment could be set up to measure the response of unaware drivers to real-life driving situations. For instance researcher could video record a traffic injunction and calculate the time from the appearance of the rear brake of a leading car and then the appearance of the brake light of the target car (Tiggs, 1987). Naturalistic observation has the merit of highest ecological validity but present several obvious limitations for the research as no independent variables can be manipulated, nor can a real control be performed on the different conditions. Moreover no measure on the process, perception and movement times can be taken, and all sort of methodological bias can modify the systematic collection of the data.

2.3. What is a Response?

Reaction times of course are about recording of time intervals, but for RTs while driving is not about a single response or a single action. RTs while driving can be analyzed decomposing the single sequence of phases that compose the response to stimuli. For these reasons is not a response time, but a series of complex actions that starts form perception and attention and include movement times that in simple reaction times studies of classic are not always relevant. In traffic psychology there are different studies that measure the time of the reaction in different ways, considering just the first reaction or the pressure on the brake, creating different time intervals that are not always easily comparable. Moreover different instrumentations are used to record reactions, and each instrument have different feature regarding software and hardware, with different frequency of recording of sensors and different working modality of the equipped car, and as we are talking about small intervals of time, milliseconds counts.

Then, to measure the psychological processes also is important to relate reaction times to different with observable measures of the process. The most common instrumentations used in general psychology are the video recording of facial expression and non-verbal locutions, measuring of eye movement and physiological activations. We will try to use this measurement in reaction time study to create an original paradigm in measuring the effect of psychological factors in RTs.

Complex Reaction Times

Motor reactions are important to measure the process that determine the overall RT. Driving require a complex coordination of different actions, that involve upper and lower limbs in interaction to crate different and articulated movements. The response to danger is not a single monolithic response, so the answer to the question “How long does it take to react to danger” needs many answers as many are the process and movement involved.

In literature it possible to find four different phases of RT:

I. *Time requested for perception / Gaze response Time (GRT),* that is the time from the appearance of the stimuli to the first time the driver has perceived the stimuli. Note that not fully awareness may be present at this time, as automatic and perceptual elaboration of the image is done by different concurring system in the motor and occipital cortex, as well as in the cortical area that classify objects and stimuli for features and potential functions, as well as potential emotional or core affect responses (Russell, 2003; Schreij & Olivers, 2013; van der Burg, Talsma, Olivers, Hickey, & Theeuwes, 2011).

   It is possible to distinguish time needed for sensation, with its own threshold and time for creating perception. Sometimes awareness comes after the stimuli has been already analyzed and classified by the unaware driver. It last from 100-300 millisecond (Hilimire,Hickey & Corballis, 2012; van Zoest, & Donk, 2010).

II. *Time for mental processing* that is the time it takes to become aware of the stimuli and starting an evaluation of the appropriate response, that could be confirm the automatic response that may be alerted by the stimuli, or a modification and regulation control of the ongoing process.

III. *Movement time* is the time needed for the motor and muscular system to perform the first programmed movement, that usually is the lift of the foot from the accelerator pedal, that can be measured as a delta in decreasing pressure on the pedal itself. It includes the total rise of the foot from the accelerator, then the movement of the feet toward the brake and then the final brake pressure. In general, the more complex the movement, the longer the movement time.

   For these reasons the movement time should at least be divided in four different phases that have to be recorded, as every movement represent different decision and different process. For instance is possible to find a relation between reaction times and full brake pedal depression, that is the fast overall RTs were the one who lifted the foot more rapidly, in approximately 0.5 sec. while in slower responders it took much longer to fully depress the pedal

IV. *Device response time* that is time it takes the physical device to perform its response, it depends on the specific features of the braking system, presence or absence of the ABS and other advanced devices, depend on the condition of the tires and of the street, and the response of the driver becomes less relevant in this phases.

These phases that seem an obvious sequential description of the driving response to danger, are in reality specific driving behaviors that relate to different factors. The sequentiality of this act does not mean that it happens for all the reaction in the same way, or that it will follow thro for all the phases in an automatic way when facing danger. Driver is influenced by the continuous evaluation of the situation, internal dynamics that involve attention, saliency perception, working memory, expectancy and urgency we have described in the previous chapter. Motor cortex already activates a response starting from perception and drivers have to coordinate chose or inhibit the correct answer for all the process (Martin, Grimard & Alexandri, 2001). This continuous process can lead to only one reaction of the gaze, or a lift from the accelerator pedal, or could stop itself in the movement phase towards the brake and never reach a fully brake. Or the driver could decide that it would be better steer the wheel and avoid the obstacle in another way. Not always these decision could be optimal for safety driving and they could fail when the driver do not possess all the knowledge about the situation, have made errors in the evaluation process, do not possess the correct script to face the situation and so on.

By a manipulation of the condition, stimuli and information available for the driver, we want to record the different phases in order to better explain how RTs can vary specifically for these measurements.

2.4. Comparing the RTs: an integrated approach

Absolute and Relative Validity

Each of this setting has significant limitations in validity, in a continuum from internal validity to reach conclusions about causal relationships that can be made about the factor influencing RTs, to the ecological and external validity in the degree to which results generalize to normal driving conditions.

For these reasons we decide to use an integrate approach in order to investigate different aspects of the RTs and take advantage of the potentiality of the different setting. Each setting has its own advantages to investigate certain aspects and factors, so each study will have a specific focus on the psychological factors that can be better investigate in this setting.

If similar patterns of behavior are observed, with similar differences between individuals, then it is possible to conclude that those specific simulations can deliver representative and significant results with the advantages of controlled environments and hazardous situations that could not be studied in real-life driving.

It is therefore possible to supply to the specific weakness in terms of validity of the research creating and integrated relationship among setting, with a dialog on the same variables and factors in RTs in different setting. This type of multi-factorial and at the same time multi-methodological approach could help to better understand the specificity of the phenomena, better secure validity issue, and -from a methodological point of view- also give some insight on the debate of the influence of context and stimuli for the evoked response in the experimental participant.

More specifically we decide to concentrate our attention on the two main setting used in research: real-life driving and virtual simulations-driving. Naturalistic observation is few informative on the ongoing process and factors in RTs, while real-life and virtual driving could provide controlled measures with different degree of external validity. Besides using different setting and instrumentations to measure different and new aspects of RTs, this integrated approach could grant an occasion for a comparison of RT in terms of absolute and relative validity of the different settings.

When comparing driving simulator and field situation, absolute validity and relative validity are the common judgmental criterion used in research. *Absolute validity* is the numerical correspondence between the driving behavior in a virtual simulator and real-life situation (Godley, Triggs & Fildes, 2002). This index could be used to test and evaluate the external validity of a specific simulation compared to the same task in a real-life driving.

Relative validity on the other hand, refers to the correspondence between effects of different variations found in the different driving situation (Godley, Triggs & Fildes, 2002). This parameter can be used to evaluate the internal validity of the task and it can be considered that, when an experimental / methodological comparison fulfills the relative validation criteria, then the driving test can be used as an appropriate tool in driving behavior studies (Tornros, 1998).

Given all these theoretical and methodological questions remains to determine what actually can be measured, other than "times", to investigate the process that influence RTs in the different settings. In literature there are some specific studies that address the evaluation of comparability of virtual vs. real driving. They are not centered on RTs response but can give us some interesting insight on the process that can be measured to evaluate the two different contexts

Speed Comparison

Bella and colleagues (2005, 2008) conducted and experiment in real-life and simulated driving to determine the speed of travel adopted by drivers on a virtual and real highway. Speed measurements were conducted with a laser speed meter in the transition area with specific work zone signals and then the situation was replicated in a virtual simulator to compare whether the signals had the same impact on speed in the two contexts different. The study demonstrated that there were no significant differences between the absolute speeds kept by the drivers. On similar experiments Bella (2008, 2012) performed a validation study focused on the speed kept on deceleration lanes of virtual and real highways and to assess lateral position of drivers in relation to risk on rural crest vertical curves. Results showed similar speeds recorded in the deceleration lanes for the virtual simulations and the real-life data, and the driving simulator proved its efficacy predicting real-life results useful to road design process.

Eye Movements

To evaluate driving simulators Underwood and colleagues have compared hazard detection in three different setting: on real-life driving, while watching short video clip recorded from a vehicle moving through traffic, and while driving through a simulated city in a fully instrumented fixed-base simulator. Results showed that a similar pattern (relative validity) was identifiable, showing the notorious “experienced drivers” effect, with more experienced drivers and especially professional drivers, scanning the road in a different way than novice or less experienced drivers, in both three contexts.

In particular the measure earlier eye fixations on hazardous objects for experienced drivers were significant constant in the three setting compared to the novice drivers.

Absolute validity would have involve the same scenarios being used on the road and in the simulator, and the same responses recorded in each, but the relative validity of the simulator was established by the observation of similar visual patterns both experienced and novice drivers suggesting that hazard perception can be used in addition to RTs for the comparison of perceptual-motor skills.

Heart Rate Variability

Hear Rate (HR) reflex the continuous activity of the sympathetic and the parasympathetic nervous systems, with sympathetic able to increase HR variability and parasympathetic to decrease HR. In particular heartbeat interval (HRV and NN interval) is the measure of the influence of these two systems on heart beat (Malik et al., 1996) and there direct relationship between automatic regulation and cognitive functions of the driver, regulated by the prefrontal cortex (PFC), that is the portion of the cortex that receive and interprets sensory inputs and regulate the executive functions we are considering in this research: decision making, selective attention, and working memory (Merian & Kessler, 2008; Miller and Cohen, 2001; Thayer et al., 2009).

Mental and visuomotor workload in driving simulations could be measured by Fisher's linear discriminant analysis to frequency filtered electroencephalogram (EEG) (Dijksterhuis, de Waard, Brookhuis, Mulder, de Jong 2013). But as the use of functional magnetic resonance imaging is not compatible with normal driving condition, especially in real-life driving (at least for our structure), HR is a particular is a particularly valuable index to study.

In a recent research Li, Zhao, Xu, Ma, & Rong (2013) compared drivers' electroencephalogram and electrocardiogram values while real-life driving and driving in a simulator in order to understand the ecological validity of virtual simulations (Meehanet al., 2002). Physiological measurements in fact could provide an important index of an individual's presence in the virtual environment, and permit a comparison of the simulated vs. real-life driving experiences (Boutcher and Boutcher, 2006; Callister et al., 1992; Lane et al., 2009).

Results showed that driving simulation is absolutely effectiveness in straight sections and large radius corners sections as those responses resulted to be similar to those observed in comparable real world scenarios (Insko, 2003; Meehan et al., 2005). In fact the differences from baseline to driving was similar between real-life and virtual driving, with a very strong correlation between simulated and on-road driving values (r=0.90) indicating good reproduction of the real world driving experience as to grant good levels of immersion and presence while driving.

However in terms of absolute validity Mean Heart Rate and Maximum Heart rate were nonetheless significantly higher during on-road drives then simulated one, suggesting that the absolute response between virtual and real driving are different in terms of activation and executive function regulation. Li et colleagues suggest that: *"For both research and evaluation purposes, it is critical* *that we better understand the impact of the driver's perceived level of risk or difficulty during simulation on their driving behaviour and physiological responses.*"

Starting from these findings, we hypothesized that the sensitivity of HR variability to even mild changes in stress, cognitive workload and decision making during (Johnson, Chahal, Stinchcombe, Mullen, Weaver & Bédard, 2011) both simulated and on-road driving (Mehler et al., 2009) is an important marker even for studying RTs while driving.

Emotional Response

In the end we consider another variable to be considered in our study, that is the emotional response of the drivers.

According to Frijda (1986; 1988; 2007) emotions can be considered as specific changes for action readiness, as response to relevant event for the person's concerns. Emotional behavior is dependent on the goals of the subjects and action readiness is more specifically the preparation for reaching this particular goal. So if actions readiness is embodied thru emotions to reach and react to particular objective relevant for the individual, they seem to play a crucial role also for driving. The situation of RTs task present all the crucial event as a salient stimuli, dangerous stimuli for the safety concern of the driver is at play, and the driver has the goal to safely avoid an accident. Emotions, are not only considered here in terms of generically activation or arousal that faster RTs, but as a factor that drive and motivate the driver's behavior.

Moreover emotion is also communication. The debate about the function of facial expression present now two main prospective (Russell, Bachorowski, & Fernández-Dols, 2003). According to one prospective facial expressions have their main value as external expression of emotions. Authors like Ekman and Izard consider facial expression as involuntary, immediate, spontaneous and universal manifestations of discrete emotions (Ekman & Friesen, 1971). Every base emotion is characterized by a facial program composed by a specific configuration of facial muscular movements.

The other prospective sustain that facial expression have in primis a communicational function (Fridlund, 1994) as they manifest the intention of the subject. They have a social value and they are influenced by the social (and cultural) context, that can determine the manifestation and interpretation of the different facial configurations (Fernández-Dols, 1999), can be regulated and assume different meanings (Gross, 1998). Considering both alternatives, it is interesting to monitor the facial expression while driving to understand the internal state or the communicational intention of the drivers in the different context and driving situation during and after RTs task. They will provide interesting data also for comparing the setting and better understand the driving behaviors in front of risky and activating driving situations.

2.5. Study Articulation

Considering what has been highlighted up to this point we want to respond to following questions thru a three study articulation:

- **Study 1)**
  a) Psychological factors in RTs in real-life driving: The influence in the interaction with Response times in the different phases of the process, in the most ecological setting.
  b) Influence of different stimuli on the RTs as function of the interaction with a warning system that manipulate driver's expectations and urgency of the brake.

- **Study 2)**
  a) In depth analysis of eye movements, investigating the heart rate variability and facial expression during RTs tasks for a better insight on ongoing process that influence RTs.
  b) A direct comparison in terms of relative and absolute validity of the RTs measured in real-life driving and a virtual reproduction of the same task and setting in a simulating driving: comparing times and subjective experiences in order to assess the influence of virtual context and validate the task in different driving situations.

- **Study 3)**
  a) Test the impact of higher levels of simulations on the effects measured in the first two studies: translating the manipulation of expectations in RTs to high risk context that cannot be studied in real-life driving such as pedestrian crossing
  b) Comparing the impact of expectations in a more realistic simulation and in an urban environment by interacting expectancy and urgency with road signs and expectancy of pedestrian crossing.

As our interest lays on general RTs, and modification of psychological factors as function of drivers' expectations we would refer to a general population of drivers, in order to compare gender and age variability. Moreover for a comparison of driving in real and virtual setting we would prefer to study a healthy population, with no influence of specific risky attitudes on overall RTs.

Chapter 3
Study 1

RTs in real-life driving

The role of attention and emotions in decision making process

3.1. Objectives

The main aim of this study is attempting to produce a model of the influence of the RT accounts for the psychological variables in a context as much ecological as possible like that of real-life driving. From a theoretical point of view, we want to show the modalities through which expectations and urgency create different psychological reaction times processes in the driver. We hypothesize that an experimental manipulation of expectation will affect RTs through different regulations of the attentive system, decision-making process, and emotional regulation system.

From a methodological point of view, expectations and predictability levels will be manipulated by an advanced warning system created for the experiment with different accuracy grades in warning potential dangers. Reaction time will not be considered as a single time interval, but will be investigated in the developing of its whole interval of the reaction. The driving reaction to the danger will be therefore analyzed throughout all its phases, from stimuli appearance, to stimuli sighting, to every single movements made by feet on the driving pedals. Moreover, since we want to include the specific processes characterizing the "human factor" in the reaction time, facial reactions of the drivers will also be monitored and their gaze will be monitored with two dedicated video cameras. Beliefs and opinions of driving process will be analyzed to obtain a better insight of the psychological process that characterize the task and to understand the strategies with which the advanced warning system has been used and experienced.

Operationalization of Psychological Variables.

In order to build a model for the influence of RTs that accounts for psychological variables in a context as much ecological as possible, the psychological dimensions manipulated by expectations' variations will have to be operationalized, to make them measurable and quantifiable in a real and safe driving context.

According to the existing literature, we focus on four main aspects that will be operationalized to create an ecological condition able to manipulate the conditions in which the driver will have to react to the danger: 1) perception and visual attention, 2) decision making / working memory 3) emotional regulation system. These systems work together and in parallel, and at the same time they will be operationalized by a setting and a sequence of unique stimuli for all these three features, but for operational reasons we will analyze them one at the time, highlighting the main characteristics of operationalization in variables of these systems.

1. Perception and Visual Attention

With perception and visual attention, we refer to a branch of research that investigates on visual field, on focused, diffuse, selective attention and on the reconstruction of the perceptual field, starting from distal stimulation (Gordin, 2010)

We refer, in particular, to visual perception, since it is considered the primary element in driving, but the same goes for the other senses, particularly hearing, and view/hearing integration. To self create a visual representation a set of steps follow each other, and in each step, the involved sensorial organ and cerebral areas analyze and reconstruct reality starting from perceptual clues coming from sensorial organs, filtered and elaborated by different criteria: from the shape to the color and the relevance. Visual attention works in parallel to direct the resources and can optimize the visual field by ignoring or identifying selectively some stimuli. Such elaboration is effective and efficient but it can be subjected to issues and limitations. Trying and studying this process with respect to the times of reaction to danger means creating a stimulus capable of passing a liminal sensory threshold, which have to be discriminated from other stimuli (articulation figure / background), *requiring that the gaze is directed to project on the fovea and trigger acquaintance*. Saccades movements have been used to study attentional shift, but do not necessarily represent the shift of attentive resources.

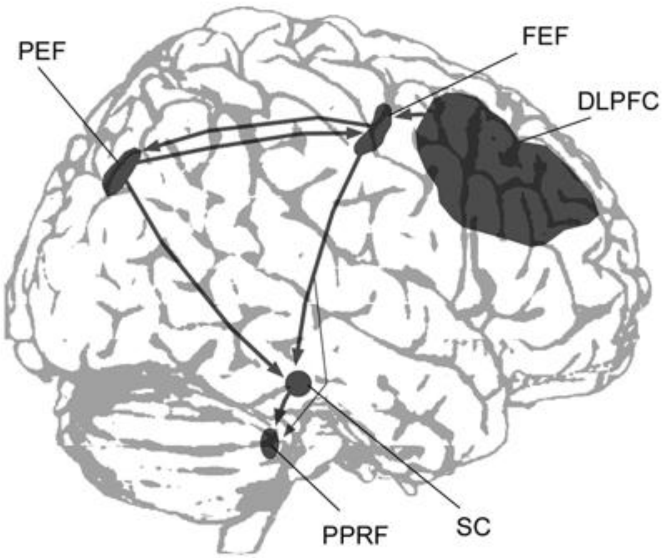


Figure 5. A simplified scheme showing the main cortical regions and subcortical structures involved in the control of saccadic eye movements: DLPFC, dorsolateral prefrontal cortex; FEF, frontal eye field; PEF, parietal eye field; PPRF, paramedian pontine reticular formation; SC, superior colliculus (Ptak, Müri, 2013)

Attention and central and peripheral perception are in close association between each other, but they are not synonyms.

The Hazard Perception Test (HPT) is a task of perception and identification of a stimulus distinguishing it from others, that is often used in research on traffic. It is a multi-component cognitive skill procedure (Deery, 1999) which has revealed to be related with experience and susceptible to learning (Crundall et al., 1999, 2002; Horswill and McKenna, 1999, 2004; Sagberg and Bjørnskau, 2006) and it allows to the subject to start a process of discrimination and analysis of the situation not just linked to the mere threshold of indiscriminate visual stimulation, but requiring to perceive a stimulus as potentially hazardous on the street ahead of them (Rosenbloom, Perlman, & Pereg, 2011).

The stimulus to be perceived that we intend to use will take these differences into account:

I. Analogously to traffic lights or brake lights vs. other cars/moving pedestrians, a visual stimulus appearing/disappearing vs. a moving stimulus will be created, in order to study diffused attention and perception of change in the visual field.

II. It will be placed in a peripheral position to the visual field of a driver, in order to measure the time necessary so that an object in the periphery of the field triggers a response in the visual orientation of the driver, with the aim of attracting his attention and causing a response.

III. As in HPT, it will not be a univocal stimulus. To be sure that it includes the perception process up to the consciousness of the occurred perception at a cognitive and emotional level, the stimulus will have different meanings, so that we will not measure just the simple and uncritical reaction to the appearance of the stimulus, but the occurred comprehension of the meaning of the stimulus. This is similar to what happen on the street, since we do not react indiscriminately to all the stimuli, but only to specific ones included in a conventional system (red light = stop; yellow light = transition imminent; green light = proceed) or a car or a pedestrian standing next to the road or close to a pedestrian crossing at a crossroads.

IV. Following the main variables able to affect visual attention, they will be stimuli with a different relevance, initially new, but becoming familiar throughout the driving sequence; there will be stimuli that are irrelevant to the task, in order to measure attention’s plasticity, and different levels of strengthening following the visual orientation, with stimuli without strengthening and a stimulus with a negative strengthening, which is the absence of an accident if promptly avoided.

We will use the specific warning system positioned in the driver’s peripheral field of view , with three different lights to which we will associate three different meanings (red light = stop; yellow = warning; green = no warning) referring to a moving stimulus: a moving foam rubber cube. This will allow us to quantify the total RTs variation and considered analytically in the different phases, with respect to the variation of perceptual and attentive features and of the significance of stimuli. Particular attention will be paid to the danger recognition phase (Gaze Response Time).

2. Decision Making:

Having three different stimuli allows us to study attention and perception, but also to quantify the decision making process.

As in real life the dangers can be anticipated by road signs that could be specific (Red light, after Yellow light), generic and not specific (warning/ crosswalk), misleading or unexpected (crossing of a vehicle not respecting the right of way, pedestrian not crossing at the crosswalk), in the same way the stimuli that we will give to the drivers will be oriented.

According to the light meaning (e.g. Red = Danger vs. Green = No Danger) the subject will have to take different decision about driving (Stop vs. Go).

The decision process is influenced by the prior knowledge, by the work memory, by the script and by emotions. In particular, decisions about known stimuli, in circumstances already faced in the past, are quicker, since they refer to thorough and comprehensive mental schemes that allow the subject to better master the situation, in a more cognitively economic manner and with adequate and functional response schemes.

I. We are going to measure a decision making process when facing a known stimulus in which well-settled driving conducts already exist (Red = danger, red traffic light = stop) and in a psychological context that could allows the subject to create an adequate mental scheme, providing every relevant element to activate the correct driving algorithm. For example: "you will see a red light: every time you'll see it, you'll have to push the brake pedal".

II. In the meanwhile we will measure the behavior when decision making schemes, facing incomplete or partial situations, will be activated: an orange light will be displayed, signaling a generic danger, that can alert the subject, but without furnishing a specific indication on the type of danger and on how it will show up, and the type of response to be followed)

III. We will create confusing and misleading situations, in which it will not be possible to use already known scripts. A green light will be displayed, which will be presented with a no-danger meaning, but actually it will be shortly followed by a danger situation (red light).

IV. Finally a set of unforeseeable and sudden situations will be created in which the subject will have to actuate heuristics or action schemes not affected by the experimental setting and not directly associable to past situations. The crossing of the foam rubber cube will not be included in the instructions, instead it will be a surprise event for the driver. The response to this stimulus will be affected by the attentive and work memory resources left over to face the danger.

V. Moreover, as emerged in the literature, danger types can be recurrent or unique. It has been suggested to make tests through a set of repeated measures to better control the effects and evaluate the learning grade, but it is essential to measure RTs also by tests made up of unique measures.

We will make up a randomized sequence of stimuli, but in which the initial stimulus will be the same for all, to be analyzed alone to allow us to gather information on responses not affected by the learning process; while a second set of responses to tests repeated for the same stimulus will be performed.
In this way we will be able to measure the difference in RTs for the four decision making processes: known, incomplete, misleading and surprise. In particular we will study the decision taken as the driver's reaction on the throttle and the brake pedals.

3. Emotions

The debate on emotions, their features, function typology, development process and display, is a question that Psychology is treating with more and more interest since the birth (and even before that) of Experimental Psychology. Without delving into the debate about which model to use for the driving dynamics, the existence of a physiologic and emotional activation that can affect the driving processes has been proved.

When facing a driving task in which the driver has to react to a danger signal or when facing a driving performance which does not admit mistakes, the emotional self-regulation system seems particularly active too.

I. If the stimulus is emotional, emotive processes will be also triggered which we will detect, to verify how their presence/absence can influence the response. The perceptions of risky situations, like a red light, a vehicle in the middle of the road, a pedestrian who suddenly cross the road, are stimuli that, for the driver, are significantly emotive. Since these stimuli should be connected to danger, activating, as a consequence, the emotional system, we expect to detect some emotional expressions which could confirm the presence of these internal states.

II. If the stimuli and the experimental situation, on the contrary, should not arouse a danger or risk situation, other types of emotive activation should activate, hence we count to find different signals and facial configurations, according to the significance given to the situation by the subject, and to the evaluation that led to develop a set of emotions.

Therefore, the analysis of facial and non-verbal expressions, can illustrates how the subject is living or has lived the danger, and can give a measure independent of the reaction times related to the processes that a real setting can activate for the driver.

The presence of emotions will be measured by analyzing the verbal expressions, the non-verbal vocal expressions and the facial expressions, before, during and after the response of the driver to the experimental stimuli and will be related to the behavior on the pedals as well as to reaction times in general.

3.2. Methodology

The Equipped Car

The vehicle used for the test was a Jaguar X-Type with automatic transmission, with standard equipment, inspected and fully working, belonging to the Centro Studi e Ricerche (CSR) - Muralto, CH. It was equipped with the diagnostic on board instrumentation of CSR and interfaced with the car by an universal interface HBM - MX 840 by the car engineer Mauro Balestra (CSR) (Figure 6). This interface granted and amplified HQ connection among a recording unit, the sensors and the car, up to 40 different recording channels. Data recording was set on temporal base up to 19.2 kHz. For these recording purposes it was recorded only at 100 Hz, that is an on line recordings of 100 data per second for each sensors.

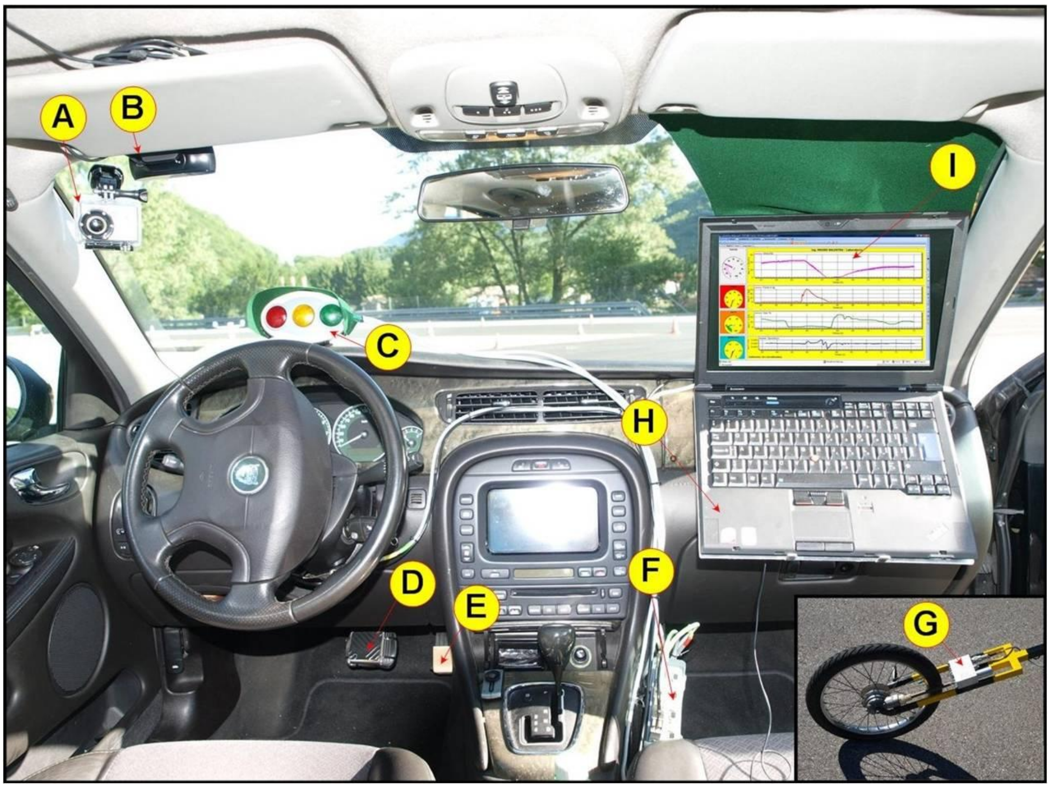


Figure 6. CSR equipped car X-Type [Jaguar] - (A) GoPro Camera HD - (B) Logitech Camera HD - (C) Experimental Warning System [CSR] - (D) Brake Sensor U-93 [100 Hz] - (E) Accelerator Sensor WA-300 [100 Hz] - (F) HBM MX-840 Data Collector [CSR] - (G) Fifth wheel Speed Sensor [MB] - (H) Real Time Synchronization [Lenovo 6478-14G S/N L3] - (I) HBM+MB Control Interface [Cattman]. © Ing. Mauro Balestra, 2011

Four main sensors where build for this experiment:

I. **Accelerator movement.**

A HBM - WA–300 sensor was used to record even the slightest movement on the accelerator pedal, recording the throttle position and at the same time giving the percentage of the total position of the accelerator, from 100% full pressure on the break, to 0% no pressure on the break when completely released, with a delta of Δ0.1% for 1/100 seconds (Figure 7).

II. **Pressure on the brake**

Sensor HBM - U93 force transducer for real-time quality control, was used to measure force (Newton) applied on the brake pedal. It is tensile and compressive force transducer for force-versus-displacement monitoring with TEDS electronic data integration automatically used for recording precise pressure measurements up to 50 kN. Delta was set up on Δ0.1 N with a recording frequency of 100 Hz, to record time of brake and intensity of the pressure (Figure 8).

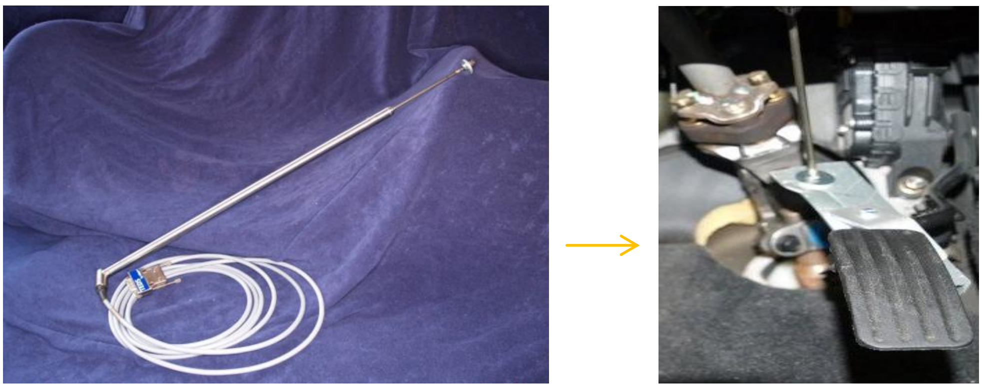


Figure 7. HBM - WA–300 Accelerator sensor for recording pressure on the accelerator pedal.

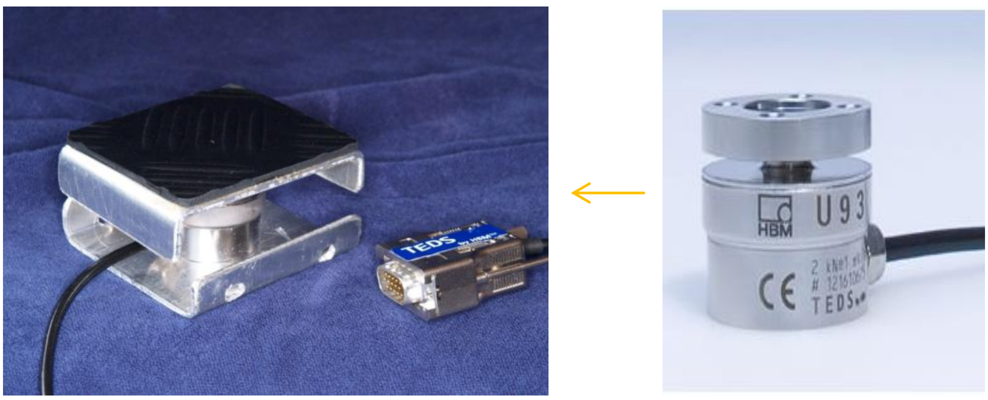


Figure 8. HBM-U93 force transducer to measure pressure on the Brake Pedal

III. Speed Recording

Fifth wheel sensor to record space/speed (MB) was used to record effective speed of the vehicle independent from the moving rotation of the tires that could be affected by electronically car systems regulation or by the ABS in case of braking. This sensor will provide on line speed at 100Hz, to provide accurate car speed and acceleration rates (Figure 10).

IV. Warning system generator.

An ad hoc warning system was created to manipulate the expectations (cfr. 3.1 and Stimuli and Track). Three LED sensors of different colors (red, yellow and green) were used. The LED technology granted immediate appearance/disappearance of the light as no time is requested from the input to the appearance of the stimuli (Kiefer et al., 1999). The light warning was recorded thru the HBM-MX 840 interface that recorded the different volts used by each light to discriminate the color of the stimuli (1V = Red, 0.8V = Yellow, 0.5V = Green) (Figure 9).

In addition to these ad hoc sensors two video cameras were used to record facial expression of the driver and visual perspective of the driver, to record the route and the external situation on the road: A *GoPro* Camera HD and a *Logitech* Camera 1080p HD. The warning system generator was used to synchronize the two cameras (initial double red light at the beginning)and the response on the brake.

Figure 9. Ad hoc three-light warning system generator and HBM-MX 840 interface for sincronization (© Ing. M. Balestra)

Figure 10. Fifth wheel sensor to record space/speed (© Ing. M. Balestra)

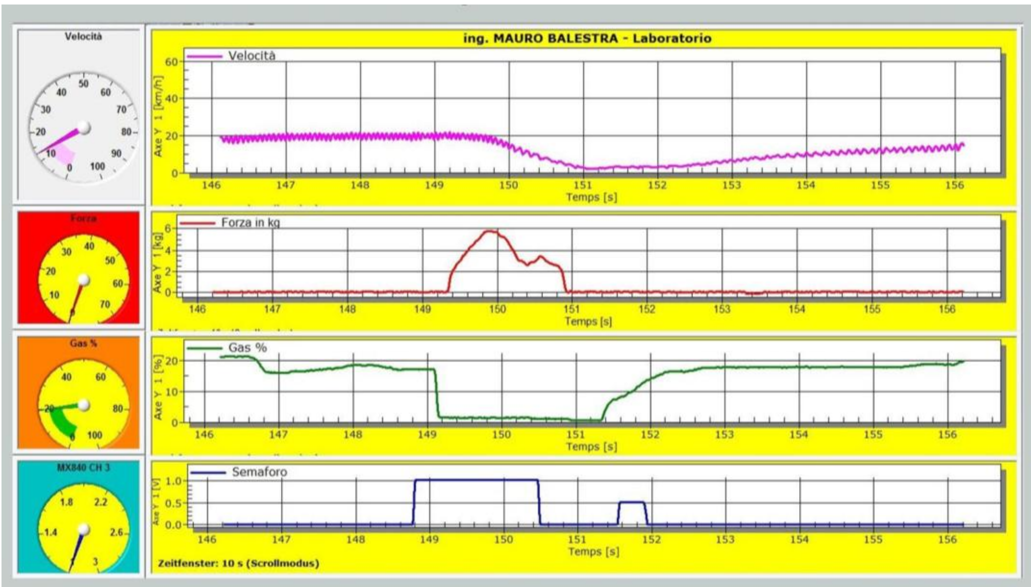


Figure 11. Ad Hoc HBM-MX 840 software interface with all sensor synchronized, to have an online and real time feedback of the driving performance during the tests.

All the sensors were managed by HBM-MX 840 software, programmed by CSR specifically for the purposes of this research, and mounted on the car. The software granted a synchronization of all the sensors by a trigger to start the recording for all channels at 100Hz.

In addition to record the data, the on car pc on car allowed to have in real time a complete overview of the behavior of the driver on the pedals (Figure 11).

Stimuli and Sequence

Manipulation of the expectations of the drivers was carried out by an in vehicle warning system, according to the principle explained in chapter 3.1.

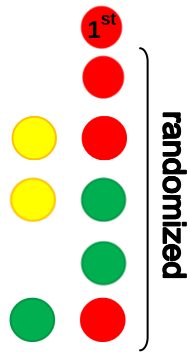
The red light was the indicator for the driver to stop the car as fast as possible.

The Yellow light meant a two second generically warning

The Green light meant for the driver no danger, drive on.

During the test the warning system generator was used to combine a randomized sequence of different stimuli to manipulate expectations (cfr. 3.1).

I. Red light (fixed 1st stimuli in the sequence)
II. Red light without warning (inside the random sequence)
III. Two second yellow warning followed by a red light
IV. Two second yellow warning followed by a green light.
V. Green Light
VI. Two second green light followed by a red light



The sequence was randomized for each stimulus, except for the first stimuli that was for all participants a red light, to test the sequence vs. first stimuli effect. Each type of stimuli inside each sequence were repeated two times, to study also learning effect, but for RTs purposes only the first sequence was recorded. This sequence was designed to manipulate the main factors that can affect RT (cfr. 1.3). In addition to these lights, no mention was made of a foam rubber cube, that was tossed at a fixed position for each participant (Figure 12). The cube represent the surprise event, was a moving and external object, to study the reaction to unexpected events (cfr. 1.3.1). Was tossed in front of the approaching car by a collaborator hidden at the side of the roadway, giving the driver approximately two seconds to brake or avoid the rolling obstacle.

Figure 12. Surprise event. A foam rubber cube tossed at the half of the straightway, in front of the moving car without the driver being previously informed

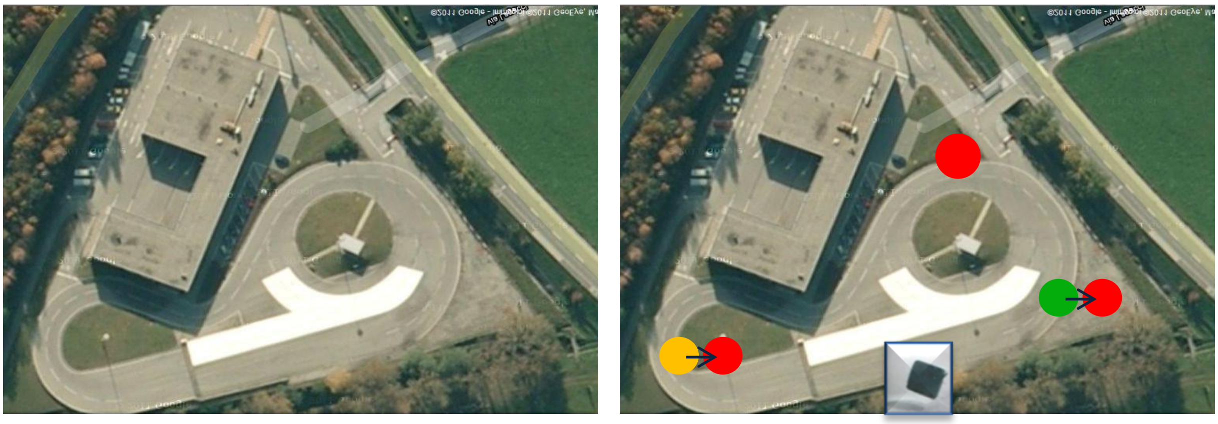


Figure 13. The controlled track of TCS, Rivera, CH, used for the experimental tests. The stimuli of the randomized sequence would appear at fixed positions in the track while the driver was pressing the accelerator

Track and Route

The controlled track used for the experiment consisted of small circuit where the driver speed could not exceed 40 - 50 Km/h. It has one straightway, two right curves and one left curve. The stimuli were programmed to appear always in an accelerator phase, in order measure the RTs that started when the driver had the right foot on the accelerator. The foam rubber cube was tossed at the half of the straightway, when the car reached a fixed point (Figure 13).

Procedure

Drivers were introduced to the experimental task as a research RTs.

They were instructed to react as fast as they could to the appearance of the red light while driving. No demonstration of the light appearance was made in order to preserve the effect of the first time, and avoid learning effects outside the experimental task. Drivers drove for one lap on track to acquaint themselves to the car and the track, with no stimuli, and then the experimental task would subsequently begin.

Drivers were encouraged to keep a constant speed, as speed can impact RT. Driver ranged around a mean of 25-30 Km/h far all subjects (cfr. 3.3.) to simulate RTs to an urban speed scenario.

No mention was made to the external surprise event drivers had to face, that was tossed out in front of the car at the end of the driving test. The mean duration for each experimental driver was about 4-5 minute long.

After the test drivers parked the car and a straightaway interview was made by the psychologist to understand the levels of expectations experienced during the task and, in particular, the feelings and the reactions to the surprise event.

Informed consent was signed by all participants after a debriefing session.

Sample

Thirty subjects participate to the test, controlled for age (*M* = 44, *SD* = 15) (Figure 14) and gender (Male = 15, Female = 15). Body Mass Index (BMI) was also recorded (*M* = 24.1, *SD* =3.5) to control the influence of weight and height on deceleration / acceleration rates during the braking maneuver. All subjects were healthy and with the driving license at least for more than 2 years.

Unfortunately for only 21 subject was possible to record the data from the surprise event, as for 9 subjects it was not possible to keep the surprise event hidden for question of logistics, therefore it would have not been an unexpected event at all and was not performed for those 9 drivers.

The sample for the surprise event result then composed by: Male = 13, Female = 8; aged *M* = 43.7, *SD* = 15.2; with BMI *M* = 24.0, *SD* = 3.0 (Figure 14).

All subjects participated voluntary to the task, with no monetary compensation, and were selected in order to build a stratification of the sample more near to a normal distribution of the two variables.

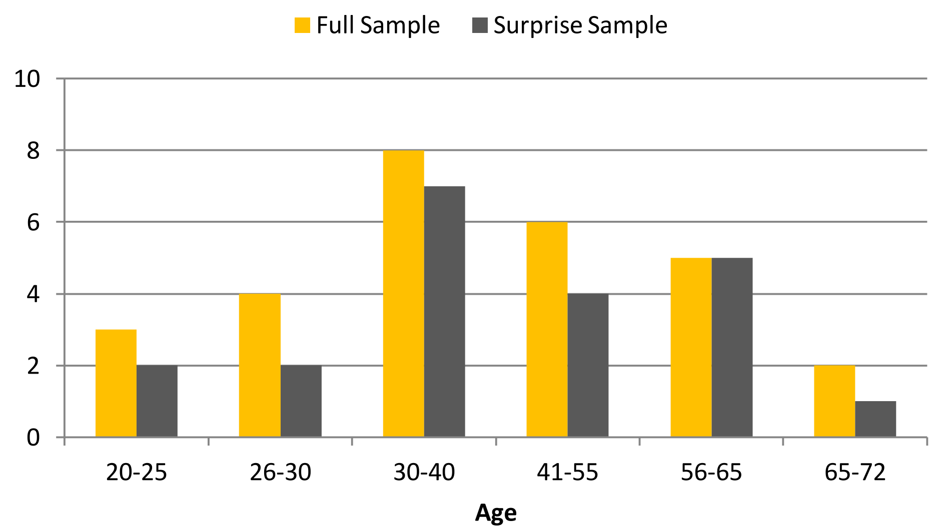


Figure 14. Age distribution of the samples used for the analysis of the Study 1.

Calculation

To understand the processes ongoing during these crucial issues, measuring the overall times may be not sufficient to explain systematical time variation nor critical situations in which the driver perform no response.

For this research we have considered a model that include also the driver's perception phase and facial expressions, along as a systematic fragmentation of five main actions on the accelerator and brake pedal (Figure 15).

A. Perception Time / Gaze Response Time (GRT)

Time interval from the appearance of the experimental stimuli to the first shift of the driver's gaze towards the stimuli. Note that not always saccade movements mean a movement of attention or overall aware perception of the stimuli by the driver (Belopolsky & Theeuwes, 2012). Sometime peripheral view can be used to detect the stimuli (Hoffman, Subramaniam, 1995; Zhao, Gersch, Schnitzer, Dosher, Kowler, 2012). Some research have faced this problem discarding recordings or considering GRT as zero (Aust, Engström, Viström, 2013), while still there was a moment for the driver that become aware of the presence of the stimuli.

For this reason to measure this perception time we may use also the first perceivable reaction of the driver after the appearance of the stimuli, that is movement of facial muscle or postural change in the driver, to evaluate if this time can be overlapped to GRT as a measure of the perception time.

B. Decreasing pressure on the Accelerator (LA)

Time interval from the previous phase to the first decrease on the pressure on the accelerator pedal. It will be monitored the percentage of the accelerator pressure, and the interval to determined within a delta of 0.1% decreasing pressure on the accelerator pedal.

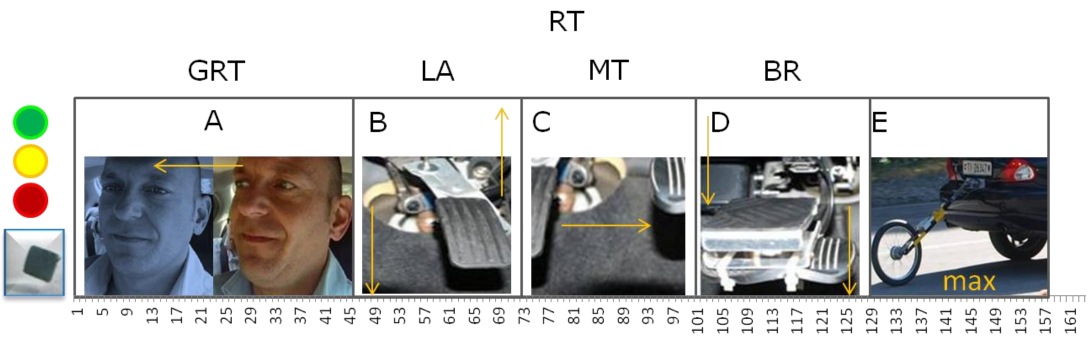


Figure 15. Phases of the Reaction Process considered for the calculation of RTs

C. Completely Rise the Accelerator (RA)

Time interval from the first decrease on the accelerator pedal, to the complete release of the accelerator. That is the time requested to completely lift the foot from the accelerator (0% pressure on the brake).

D. Movement Time (MT)

Time interval from the last time the foot was on the accelerator to the first time a pressure on the brake start to be recorded. The delta for the end of the movement time will be considered when a force of 0.1 Newton will be monitored on the brake.

E. Brake Reaction (BR)

Time requested to build the pressure on the brake, until the very maximum pressure on the brake at soil that will trigger the first decrease on speed (Δ0.1 Km/h).

Beside quantify the temporal duration of the five phases, to the different stimuli we will also record:

- Speed of travel
- Accelerations (positive and negative) of the vehicles in the different phases
- Pressure on the brake

- Time requested from the appearance of the stimuli to the maximum pressure on the brake
- As well as facial expression for the whole duration of the task
- A post hoc drivers' interview about the experimental task: duration, feelings, expectations and predictability of the stimuli.

Times will be processed thru ad hoc software that synchronizes the different sensors. While the videos will be analyzed by Noldus Observer XT Software to record action units and gaze orientation at 25 Fps (Figure 16).
As data measured by the sensors on the pedal will record at 100Hz, GRT and facial expression appearance will be calculate according the following formula

$$RT = N / r$$

$$Accuracy = \pm 1 / (\text{frame rate})$$

Where N is the total number of frame considered during the response interval, and r is the frame rate used for recording. This will be important to adjust result to compare data coming from different sources and equipment.

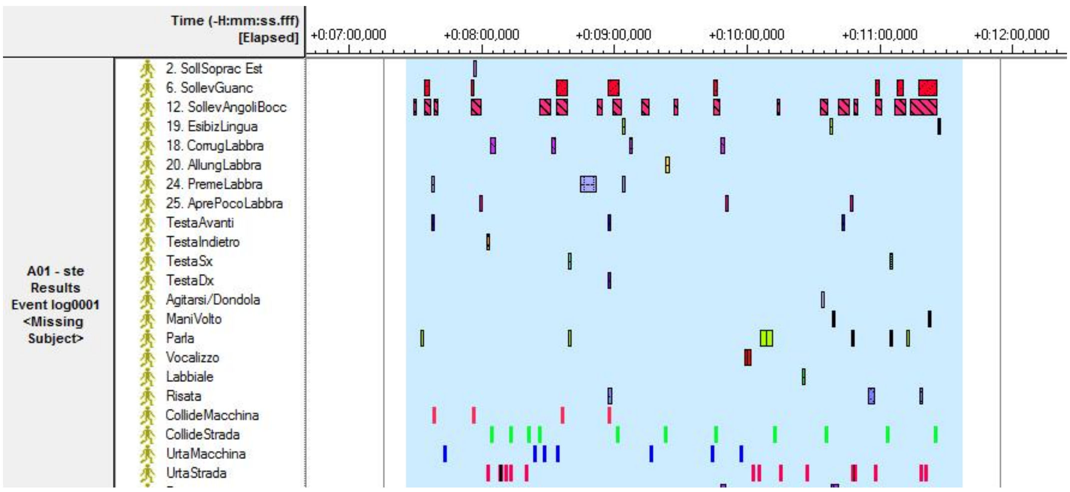


Figure 16. Example of analysis of behaviors starting from an analytical codification of driving and expressive actions, using the Observer XT software

3.3. Results

The mean speed recorded during the test was 30.84 Km/h with a maximum mean of 43.9 Km/h and a minimum of 25.6 Km/h. It is safe to assume that the following result could be applied to the urban driving context, while for suburban or highway roads it would need other test.

Total Reaction Times

Considering all type of stimuli, considering all the process and driving situations, the total reaction time from the appearance of the stimuli to the moment the driver applied the maximum force on the brake pedal was 1.18 seconds (*SD* = 0.22) with a factor of almost 2, with minimum mean of 0.93 seconds and a maximum mean of 1.97 seconds (Figure 17), but as Summala (2000) pointed out the calculation of central tendency parameters taken from a variety of situations can masks important variance and is at risk of giving biased and arbitrary estimates of drivers' RTs. In fact RTs vary systematically and significantly for type of stimuli in according to the hypotheses formulate by literature (Table 1).

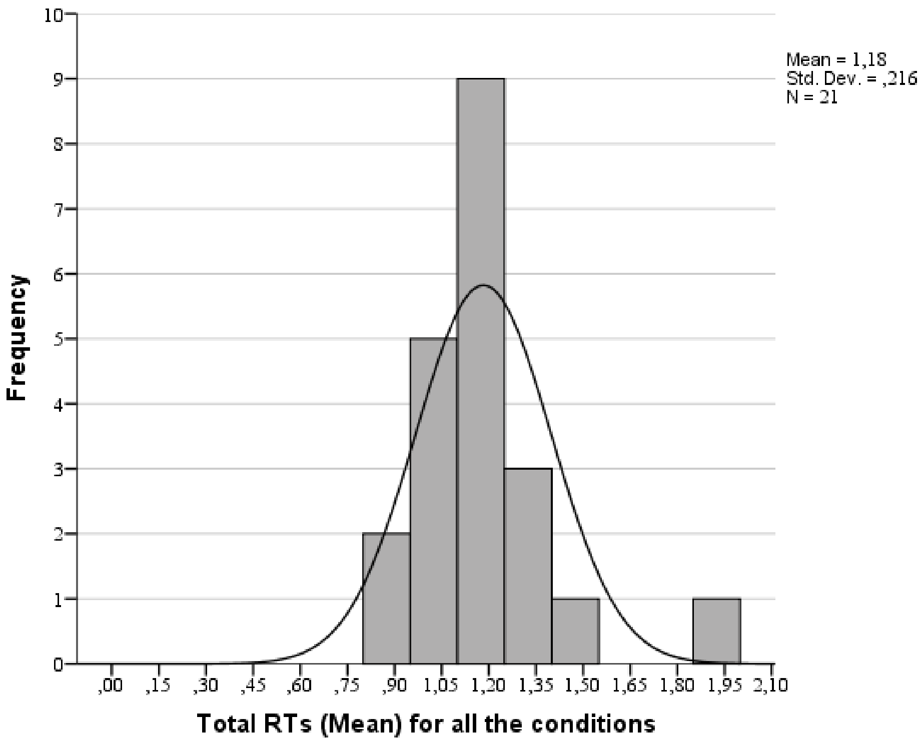


Figure 17. Distribution of overall Reaction Times mean values for all drivers and during all the experimental conditions.

Table 1. Reactions Times x Stimuli (seconds)

Stimuli [a]	Total RTs				Differential Thresholds		
	Mean	*SD*	*Minimum*	*Maximum*	*25%*	*50%*	*75%*
Warning	.91	.21	.60	1.42	.76	.88	1.02
Expected Red	.99	.23	.65	1.63	.88	.96	1.04
Misleading Warning	1.18	.29	.68	2.06	1.00	1.15	1.31
Surprise Event	1.28	.20	.94	1.83	1.17	1.25	1.44
1st Stimuli	1.39	.47	.93	2.66	1.06	1.19	1.56

a

Different stimuli selected from the randomized sequence: 1st time the red light appear in the test; Red light shown for the second time inside the randomized sequence, Two second yellow light warning followed by red, Misleading green light before a Red light, Surprise foam rubber cube event. (cfr. chapter 3.2)

Table 2. Reactions Times x Phases (seconds)

Phases [a]	Total RTs				Differential Thresholds		
	Mean	*SD*	*Minimum*	*Maximum*	*25%*	*50%*	*75%*
A) GRT	.21	.10	.10	.56	.15	.19	.24
B) LA	.14	.05	.07	.22	.09	.14	.18
C) RA	.09	.03	.04	.19	.07	.08	.10
D) MT	.18	.06	.10	.34	.13	.19	.21
E) BR	.59	.13	.28	.88	.51	.59	.68

a

A) Gaze Response Time: Time interval from the appearance of the experimental stimuli to the first shift of the driver's gaze towards the stimuli. B) Begin Lift Accelerator: Time interval from the previous phase to the first decrease on the pressure on the accelerator pedal. C) Completely Raise the Accelerator: Time interval from the first decrease on the accelerator pedal, to the complete release of the accelerator. D) Movement Time: Time interval from the last time the foot was on the accelerator to the first time a pressure on the brake start to be recorded. E) Time requested to build the pressure on the brake, until the very maximum pressure on the brake. (cfr. chapter 3.2)

As can be seen from the descriptive statistics in table 1 there is a huge influence of meaning and expectations manipulated by the stimuli in the distributions of overall RTs. The differences among the conditions are statistically significant $F(4,21) = 11.234$, $p < .000$, $\eta 2 = .364$.

Pairwise comparison on estimated marginal means (Bonferroni) shows that the RTs to the absolute first stimuli are comparable to the RTs to the unexpected event and to the surprise event : i.e. the responses to the misleading information condition (green light warning followed by red light), the responses to the surprise event (foam rubber cube) were not different from the first time the drivers had to face the new experimental task (*Mean difference* = .41, *p* = .716 from the misleading condition; and = .16, p = 1.000 from the surprise event) (Figure 22).

On the other hand the RTs to these group of unexpected/new/surprise event differ significantly from the times to the condition (Figures 18-20) where the driver knew what he/she was going to face, i.e. the response to the two second warning (*Mean difference* = .95, *p* = .001) and the response to the second time they face the red light inside the randomized sequence, once the driver is acquainted with the stimuli (*Mean difference* = .78, *p* = .001).

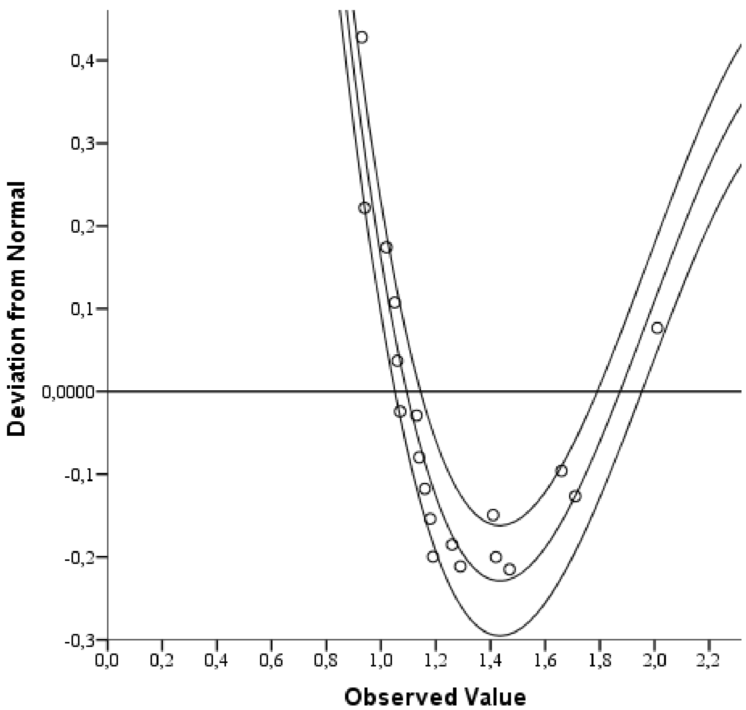
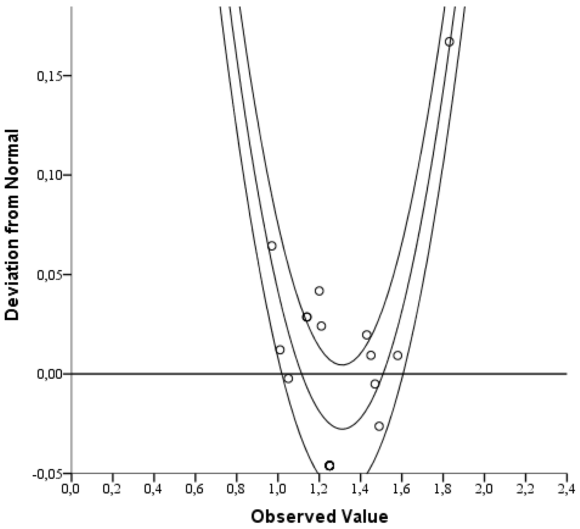


Figure 18. Distribution of Reaction Times mean values for all drivers and deviations from the Normal distribution to the 1st stimuli (red light)



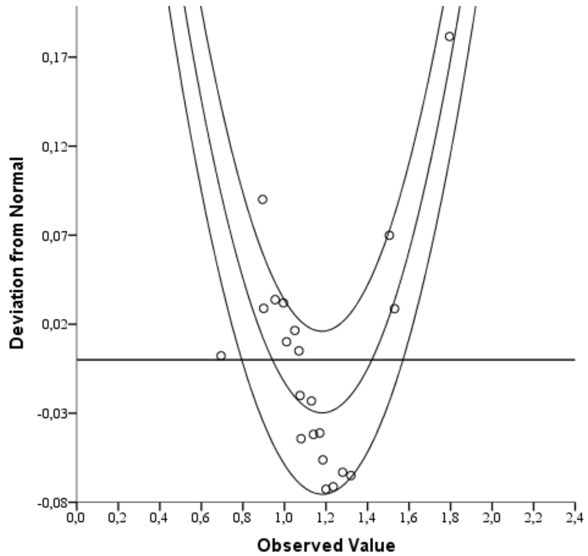
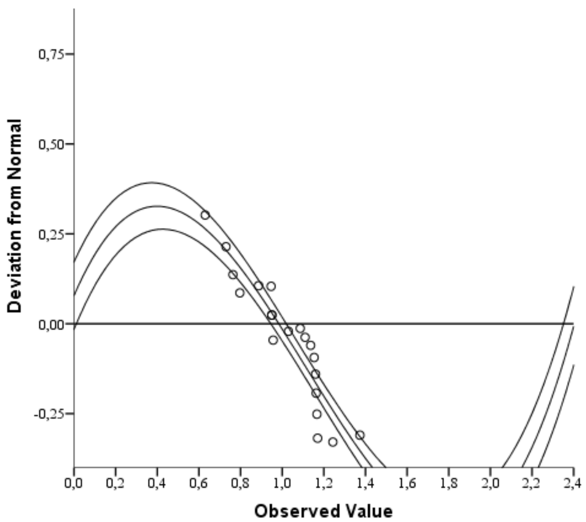


Figure 19. Distribution of Reaction Times mean values for all drivers and deviations from the Normal distribution to the unpredictable conditions: surprise event (left) and misleading condition (right).



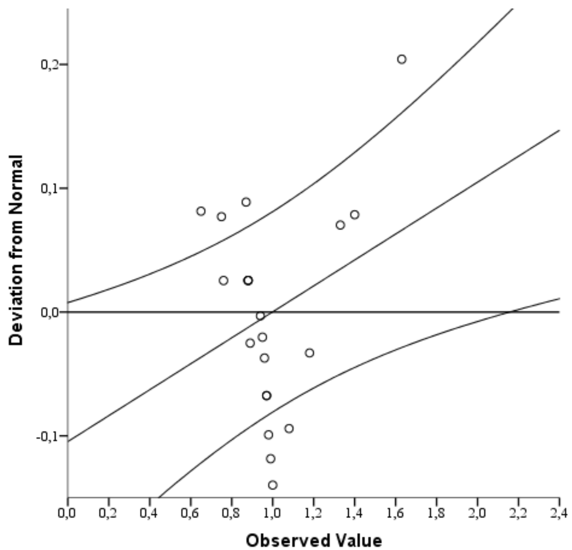


Figure 20. Distribution of Reaction Times mean values for all drivers and deviations from the Normal distribution to the predictable conditions: two-seconds warning (left) and 2nd red inside the randomized sequence (right).

Phases of the RT Process

The variations among the different stimuli generate also different pattern of the visual/motor responses of the drivers. First the different phases, that are GRT, LA, MT and BR have different durations, and do not divide equally the total RTs $F(4,21) = 139.923$, $p < .000$, $\eta^2 = .875$. In particular of the overall 1.18 mean total times, plenty .62 seconds pass before the drivers reached the brake (Table 2). That is to say that more than half of the total reaction time is spent in perceiving the stimuli and deciding that the foot should move on the brake. Yet a braking pressure is not performed and it take another .58 seconds mean to press the brake to obtain a brake pressure able to start decreasing the speed of the vehicle. This means that the RT task request a perception and decision making process that does not perfectly match just with the motor response of moving the foot from the brake (Figure 21).

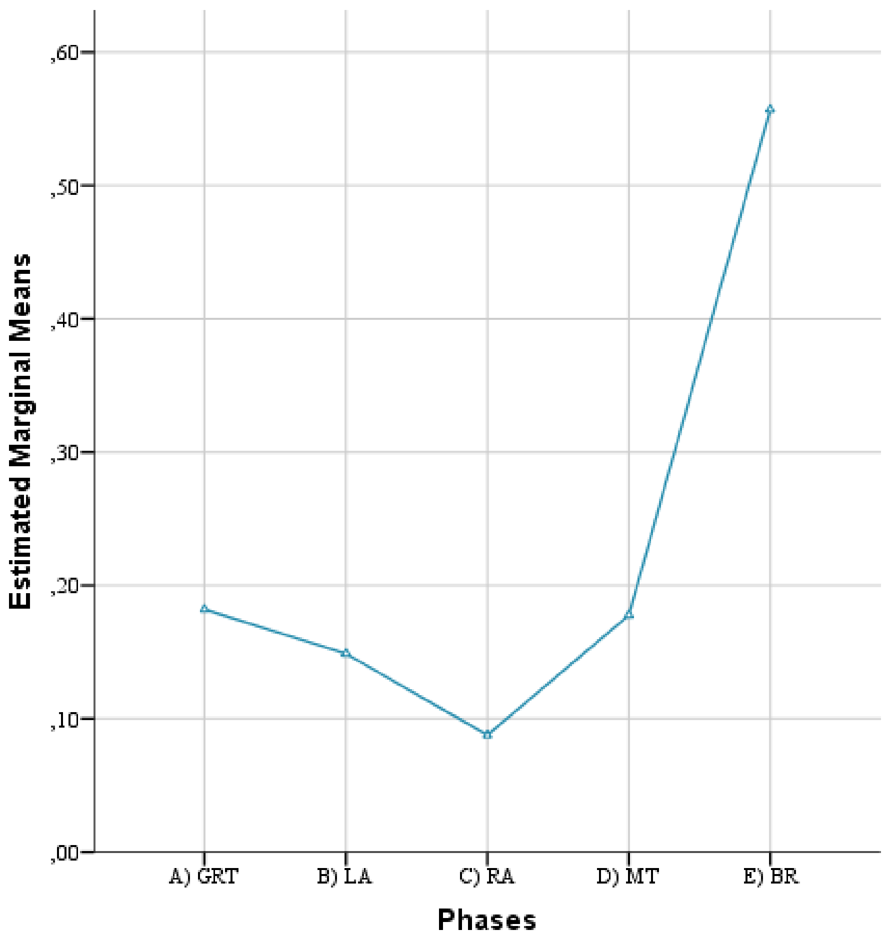


Figure 21. Distribution of Reaction Times mean values for all drivers for the different phases of the RTs (cfr. 3.2)

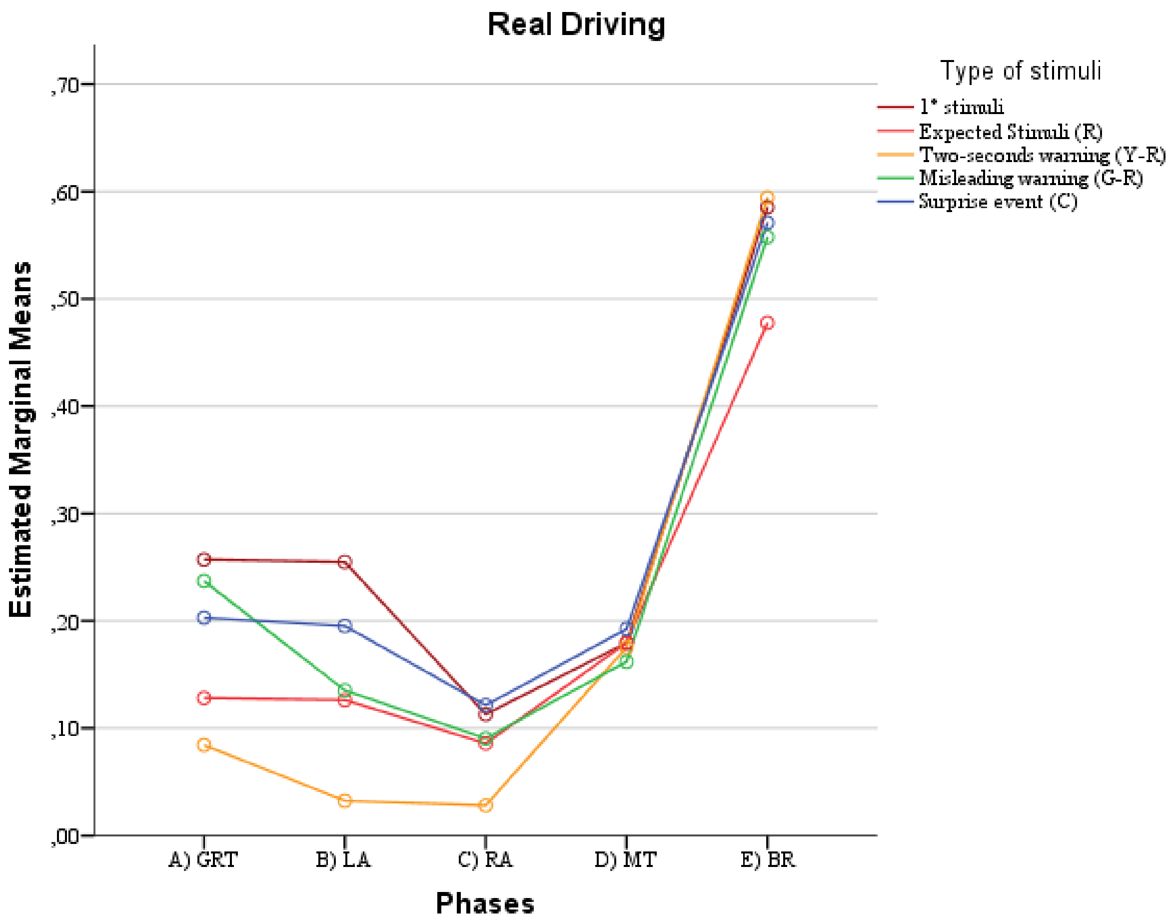


Figure 22. Distribution of Reaction Times mean values for all drivers for the different phases of the RTs and to the different type of stimuli (cfr. 3.2)

Phases and Expectations

More clearly, the impact of perception and decision making in determine RTs can be seen by the influence the different expectations created by the stimuli had on the “pre-motor action” response. As can be seen in Figure X the different levels of danger expectation did not impacted the movement time from the accelerator to the brake (MT) nor the pressure on the brake (BR): when the driver has seen the danger, understood that a brake is need and then decide to perform an action, then the motor response is not dependent on the type of situation. All the differences in the RTs are explained by the perception, visual attention and decision making phases. In fact considering the overall interaction effect of Phases x Stimuli it result significant $F(16,21) = 2.655$, $p = .003$, $\eta^2 = .117$, but the eta square is not very strong. In fact, as can be seen in

Figure X, for the MT and BR there is no interaction effect at all while explain strong part of the variation for the GRT and LA/RA phases.

Going into an analytic analysis of the data is possible to calculate different trajectories that the expectations create on the reaction of the drivers.

A. <u>Gaze Response Time</u> (GRT)

For GRT is possible to find two trajectories: the group of predictable stimuli (two seconds warning and the red inside the sequence), and the group of unpredictable stimuli (surprise, 1st, and misleading stimuli).

I. Expectable stimuli are detected in a range of 0.08 - 0.12 seconds, from the two seconds warning signal response *M* = .08, *SD* = .08, *p* = .001*; to the 2nd Red in the sequence *M* = .12, *SD* = .08, *p* = .004.

II. Significant slower trajectory can be found for the responses to unexpected stimuli, with a GRT that ranged from 0.20 - 0.26 seconds (1st stimuli: *M* = .26, *SD* =.20; Misleading stimuli: *M* = .24, *SD* = .18; Surprise event: *M* = .20, *SD* = .12). Knowing what to expect grant a faster orientation of attention toward the target stimuli when they appear in the driving environment, while not knowing what will appear, requires more visual attention resource that result in slower detection of the target elements when they appear.

* Note that the *p* values in this session for the Pairwise comparison on estimated marginal means (Bonferroni) refers to the comparison with the misleading condition, as the median representative of the unexpected group. There is no need to report the value to each pairwise comparison, that resulted significant for the other two conditions as well.

B. Beginning Lift the Accelerator (LA)

After having directed the gaze toward the stimuli, the manipulation of expectations amplifies once more its effect, as the discrimination and decision making process become involved. It is possible to identify three different trajectories: I) Responses to the two second warning, II) Responses to red light inside the random sequence or after the misleading event, III) Responses to the surprise event and to the 1st stimuli.

I. Stimuli and Temporal certainty: Two seconds warning

In this condition the driver was expecting a red light to appear and knew that he would have to brake. Drivers start diminishing the pressure on the brake in a mean of 0.03 seconds (*SD* = .06) that is barely the time needed for the brain signals to reach the lower limbs. The anticipatory information pre activated muscles' isometric contraction thus the faster beginning of the response more rapid than the other conditions ($p < .000$).

II. Stimuli certainty but Temporal uncertainty: Reds inside the sequence

In these two conditions driver had no warning (2nd red in the sequence) or had a misleading warning on what would have come next (Misleading green light before a red light), but knew how to react at the red stimuli, as they have already experience a red light before, only they did not expect it coming.

This condition is significantly represented by the data, as the beginning of the reaction is significantly slower than the warning condition, but significantly faster than the Surprise and new condition. Drivers react in a mean range of 0.13 (*SD* = .08) seconds of the second red inside the sequence, to an almost identical mean of 0.13 (*SD* = .11) seconds for the misleading condition. It is interesting to note that while for GRT the misleading condition was insert in the trajectory of the surprise event, once the stimuli is recognized, it follows the path of stimuli already elaborated and faced.

III. Stimuli and Temporal uncertainty: Surprise and 1st stimuli

In these conditions after having detected a stimulus, the decoding of its meaning require the longest time before starting executing a motor response, diminishing the pressure on the accelerator.

The driver did not know a stimulus was coming, nor they knew what would have been, and additional time is requested to process the visual information and decide whether and what motor reaction is requested, as they had no previous experience with the task. This is reflected in the response times, with a mean range of 0.19 (*SD* = .12) seconds to began a motor response to the surprise event, up to a mean of 0.26 (*SD* = .20) seconds for the 1st stimuli.

C. <u>Rise the Accelerator</u> (RA)

This is the more rapid phase of the entire RT process.

To completely rise the foot from the accelerator it is possible to find two trajectories: the response to the two second warning condition vs. all the other conditions. In these phases is in fact possible to notice an effect only in the condition of

I. Stimuli and Temporal certainty (two seconds warning) where the action to perform was clear since the beginning of the motor response, and the muscle isometric contraction may have already influenced the response on the accelerator. To rise completely the foot drivers take a mean of 0.03 (*SD* = .04) seconds.

II. While all the other condition require similar time to rise the foot. Once the stimuli has been detected, recognized, and the decision to lift the foot has been taken, then the time to realize the motor action of the foot is similar in all the other conditions, taking a mean of 0.09 - 0.12 seconds.

D. Movement Time (MT)

Once the decision to brake is taken the, time requested to move the foot from the accelerator pedal to the brake pedal is exactly the same for all the stimuli. As found in the previous literature MT is 0.18 (SD = .01) seconds.

E. Pressure on the Brake (BR)

Follows the trajectory of the MT, that is once the decision to brake is taken the, time requested to press the brake pedal to the maximum force is exactly the same for all the stimuli. Drivers took a mean range of 0.47 - 0.59 seconds. The beginning of the slowing of the car due to braking pressure takes, instead a mean of .32 seconds, that is to say that while the driver reaches the max force on the brake, the braking effect has already begun. The mean deceleration rate during the whole braking process was 8,47 m/s^2.

It is interesting to note that while the time to reach the braking pressure were not different in the conditions $F(16,21) = 2.431$, $p = .081$, $\eta^2 = .157$, it was the force the driver pressed on the brake while facing the different stimuli $F(16,21) = 46.392$, $p < .000$, $\eta^2 = .699$ (Table 3).

It has to be noticed that the blocking of the tires is usually obtained with a force on the brake of about 45 - 55 Kg, so the presence of values over 55 Kg are useless in terms of the brake efficacy, but it has only a psychological value as an indication of the activation of the experimental condition aroused in the drivers, as it does not coincide the moment of the beginning of the braking action of the car, nor with the maximum deceleration of the vehicle while braking.

Table 3: Force on the Brake

	Max Pressure on the Brake (Kg)				Time for Reaching Max Brake (seconds)	
Stimuli [a]	*Mean*	*SD*	*Minimum*	*Maximum*	*Mean*	*SD*
1st Stimuli	18.5	21.6	3.2	92.0	1.39	.47
Misleading Warning	22.8	20.7	5.8	73.7	1.18	.29
Warning	28.7	28.0	5.9	107.7	.91	.21
Expected Red	34.6	31.1	6.8	102.3	1.00	.23
Surprise Event	43.5	28.9	4.9	115.3	1.25	.21

[a] Different stimuli selected from the randomized sequence: 1st time the red light appear in the test; Red light shown for the second time inside the randomized sequence, Two second yellow light warning followed by red, Misleading green light before a Red light, Surprise foam rubber cube event. (cfr. chapter 3.2)

It can be inferred from these data that the different reaction created by the manipulation of expectations had an influence on the intensity of the driver's reaction on the brake, and that supplied to the time latency that resulted in an overall faster response of the car. In particular the condition that registered the slower overall RTs, Stimuli and Temporal uncertainty conditions, present two completely opposite type of brake reactions: the 1st stimuli present the weakest pressure on brake, arousing more lately then the other while the surprise event arouse the hashes brake reaction.

Facial expressions

The result role of expectations on RTs, and in particular on the first phases of the process can be enlightened by the analysis of facial expression of the drivers during the crucial issue from the appearance of the stimuli until the end of the braking maneuver. In particular two considerations can be made. First drivers communicate thru facial expression during the RT task, creating facial configurations of emotional expressions one manipulated by the stimuli. Second and more important, there are some cases where no action on the brake was performed, and yet the recording of changes in facial expression configurations could lead to informative knowledge that can be insert in RTs calculation.

In particular:

I. inside the randomized sequence almost all drivers used peripheral view to react to later stimuli (cfr. 3.3.7. Learning effect). This issue will be better covered by the use of an eyetraking in the Study 2

II. During the surprise event the facial expression of drivers was used to assess changes in the driver when long latency time were found between the phases or when no reaction on the pedals was found at all.

In particular several drivers presented values over the overall sample mean in some or more than one phases of the reaction, and 6 presented no reaction on the brake to the surprise event.

Integration in RTs

As said before, there where situations where the driver did not performed any action on the brake pedal. In particular 6 drivers while facing the surprise event did not perform any actions, and crashed with the foam rubber cube.

When asked what happened in this situation, drivers reported that they have not “seen” the obstacle.

This kind explanation seems to impute the cause of the accident to distraction or to “failing to see” dynamics.

Just analyzing data from the pedal sensors, we would have not been able to say much about these situations.

However analyzing the video data of facial expression synchronized with pedal sensors, it was possible to see that there was an orientation of the gaze toward the stimuli, so that we can say that their attention was grabbed by the object.

Then it was possible to see some facial expression in some driver involving *frontalis* muscles: for instance a rise of eyebrow, some frown the eyebrow, lowered, as well as rise of the upper lid.

At the same time for the mouth muscles, such as lip corner depressor and lower lip depression.

As can be seen in Figure 23, a surprise face can be recognized, as well as a puzzling face at the end of the crash.

These actions can be synchronized inside the RTs process to mark the failure of the driver, helping find and explanation to the fail to react behavior.

It is possible to see an orientation of the gaze toward the moving object (A), and even before any action on the accelerator pedal (B), a fully facial expression is performed in an interval of 0.03 - 0.08 seconds.

Then the foot from the accelerator is completely lifted (C), yet there is a frowning expression on the driver's face. She has perceived the obstacle, yet no immediate action is given. Movement Time (D?) can not be recorded as the foot never reached the brake pedal for press and began stopping the car (E?).

The foot is lingering while facial expression gives way to some worry and concern, changing the posture of the shoulder and head, towards the obstacle that has -safely- hit the car.

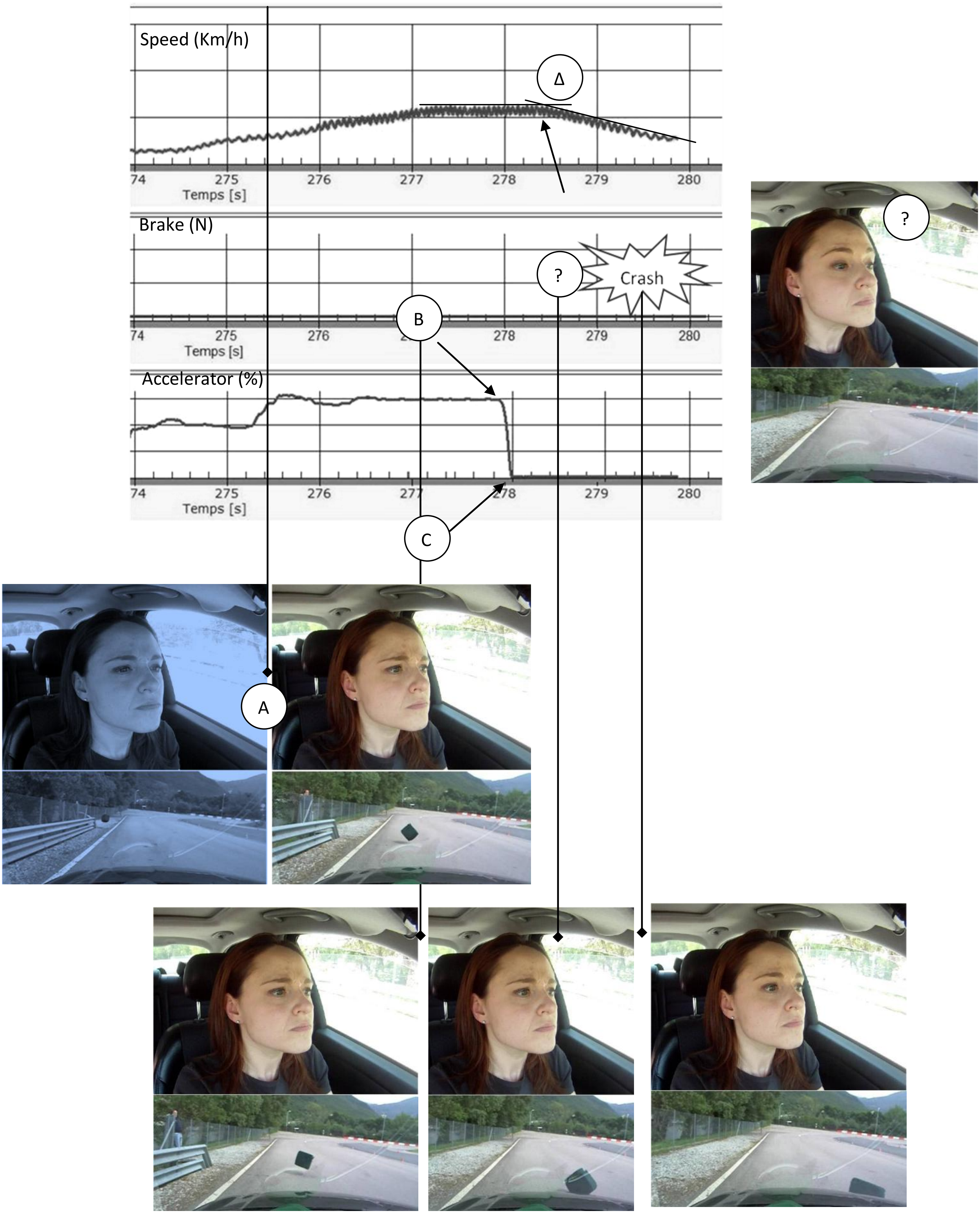


Figure 23. Reaction to the surprise event. The driver performed no action on the brake while facing the surprise event. From facial expression analysis it is possible to evaluate that the driver actually has seen the object, but after visual orientation of the gaze, no decision to press the brake is reached while elaborating the surprise stimuli. After the crash some concern configuration can be seen in the driver's face.

Figure 24. Reaction to the surprise event. Even in this case the driver performed no action on the brake while facing the surprise event. From facial expression analysis it is possible to evaluate that the driver actually has seen the object, but no action on the brake followed.
Not always concern or surprise facial configuration emerged, but mixed configurations.

Not all the facial expression display the complete set of Action Unit (AU) for surprise (1+2+5B+26), other were partial, or presented more complex and mixed emotions during the process and after the crash (Figure 24).
These expressions, could confirm that it was not distraction, rather the effect of the surprise and unexpected event may have requested more time then the TTC available for the driver. That is to say that the process to process the stimuli, the meaning of the stimuli and decision making process to evaluate whether a response is required, and what response to perform, was not sufficient to evocate a proper script (press the brake) to avoid the crash.

The aim of this analysis was not centered about the debate of emotions and facial expression, but nonetheless this particular setting and task, could help to analyze in a realistic setting the reaction to stimuli that is potentially more natural to evoke emotions then the one used in artificial and controlled setting.
Here are another examples emerging from the other stimuli situations.

Example 2: Communication and measuring Expectations

Drivers changed their facial expressions while responding to the stimuli.

In particular in the Stimuli and Temporal uncertainty conditions.

As a measurement of expectations is possible to find that when incongruence or novelty situations appear, a consequent facial expression may occur, to accompany and comment the situation.

On the car with the drivers there was always the researcher that was controlling / imputing the sequence. The presence of another person other than the experimental subject, may have influenced the subjective experience of the driver, and may have solicited the communication of emotional response.

As can be seen in example 1, when a linear situation would occur, and the expectation of the driver respected, i.e. two second yellow warning followed by the red light, no particular facial expression appear on the driver's face (Figure 25).

On the contrary, when expectations were not confirmed and incongruent element emerged, i.e. misleading green light followed by the red light, facial expression were observable in the driver's face (Figure 26). This type of response was detected for at least 20 subjects (Figure 27), and it was an interesting index of the driver condition while performing the task. Further analysis must be conducted in order to better relate the facial expression and the RTs in those conditions, as well as by a complete annotation of AU during the crucial phases, in order to better understand if a pattern of facial expression can actually measure driver's expectations, using an algorithm that could recognize crucial pattern for RTs and road safety (Figure 28).

Figure 25. Facial expression in reaction to the two-second warning condition. When a linear situation would occur and expectation of the driver respected like in the two-seconds warning, no particular facial expression appear on the driver's face. We can see that since the appearance of the warning (1) to the appearance of the red light (2) and thru the brake reaction process, the facial expression of the driver does not express any particular emotions.

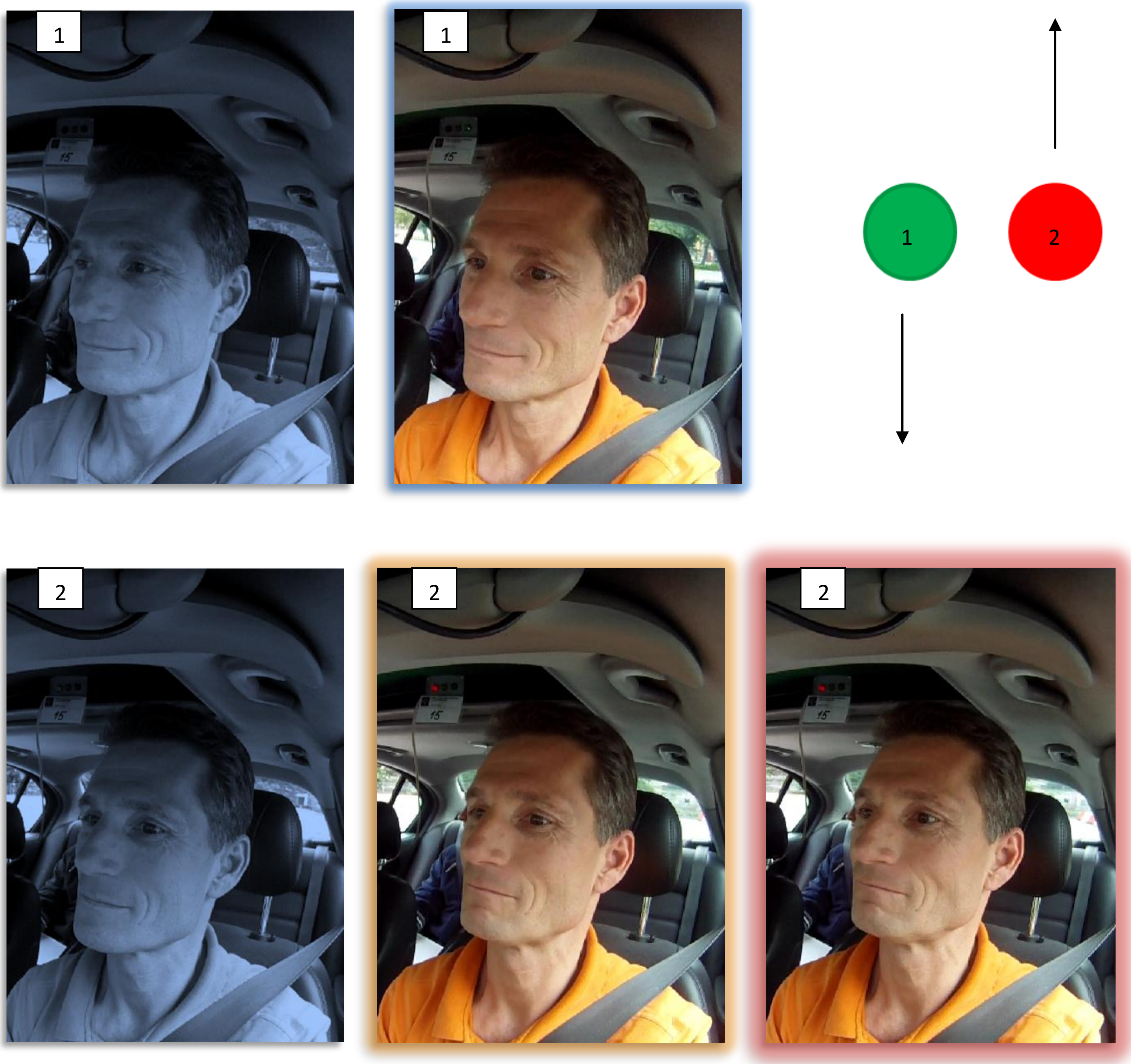


Figure 26. Facial expression in reaction to the misleading condition. When expectation of the driver are not respected, like in the misleading condition where a red light appear after the display of no-danger green light, facial expressions appear on the driver's face. We can see that at the appearance of the green light (1) the driver's facial expression is similar to the linear two-warning condition. But since the appearance of the red light it is possible to see a change in the facial expression with Frontalis and Pars lateralis movements as well as Orbicularis Oris muscle movements.

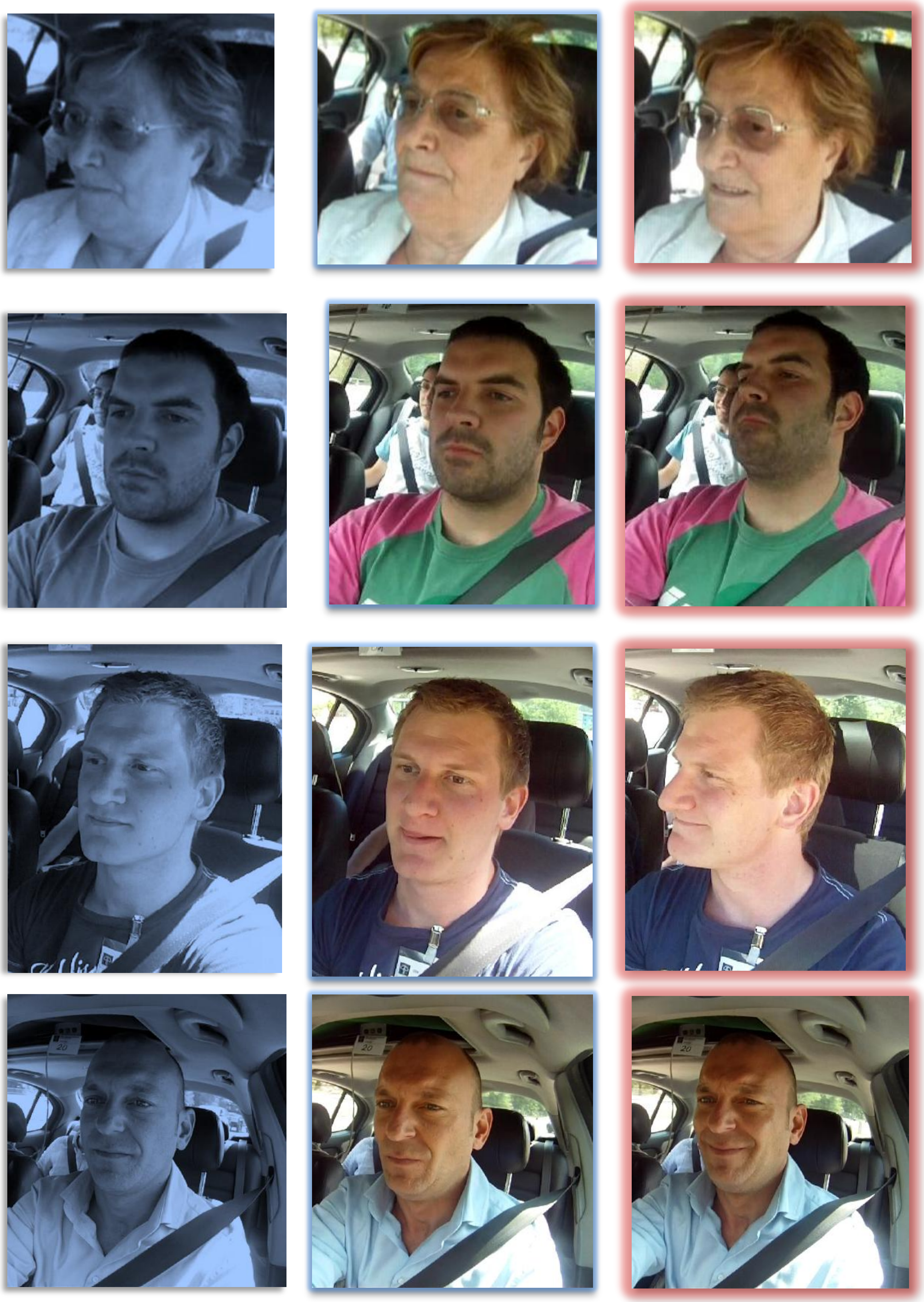


Figure 27. Facial expression facial expression with Frontalis and Pars lateralis and Orbicularis Oris muscle movements while reacting to to the misleading condition were recorded for at least 20 subjects. It is possible to hypothezies that the driver was showing his/her concern or disappointment for their expectations not being fulfilled and having to react to a potential danger while driving.

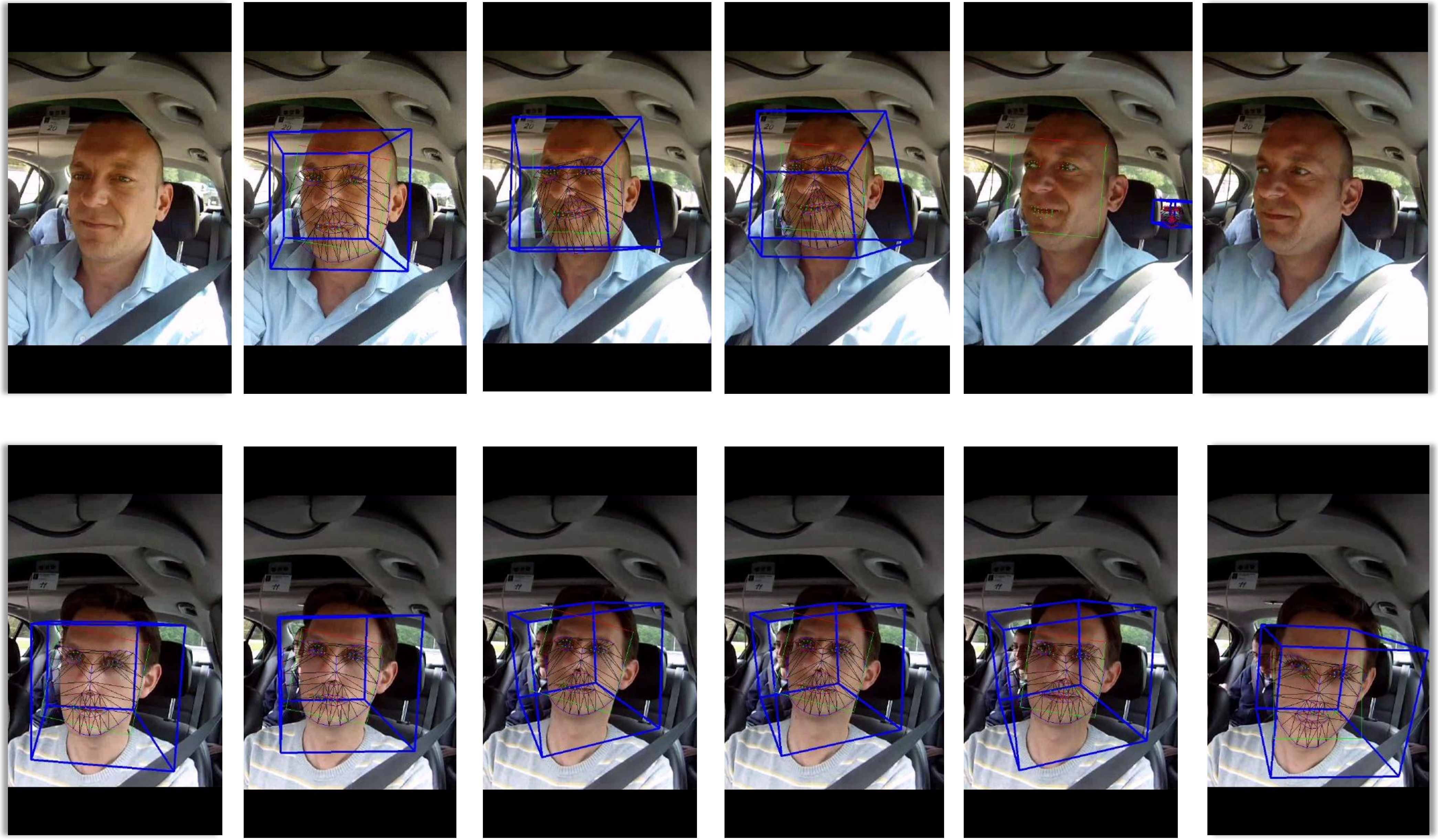


Figure 28. Using a proper software for reading facial expression while driving could help measuring driver's expectations while reacting to a certain stimuli, and by using a proper algorithm it would be possible to measure and recognize the driver's levels of attention and expectation and relate to driving parameters (like CAN BUS), to proceed towards an intelligent tutoring system that could recognize human emotions even for driving situation.

Learning effect

To control learning and sequence effect (cfr. 3.1.) the randomized sequence was repeated except for the first stimuli that was always a red light presented without warning for the first time, and the surprise event, tossed out at the end of the experimental task.

Results show that according to literature, the first time drivers had to face the stimuli, RTs are significantly slower of almost 0.33 seconds then the second time they face the red without warning inside the randomize sequence (t = 4.186, $p < .000$).

This learning effect is very rapid, as it occur only comparing the first absolute stimuli, and does not occur in the comparison of matched stimuli in the sequence (Figure 29). There are no significant difference between the two second warnings pair (t = .932, p = .363), nor between the two misleading stimuli in the sequence (t = .410; p = .686).

Moreover as hypothesized after the first stimuli, the drivers began paying attention to the warning device more frequently compared to the beginning of the test, optimizing their visual attention around the salient area of the visual

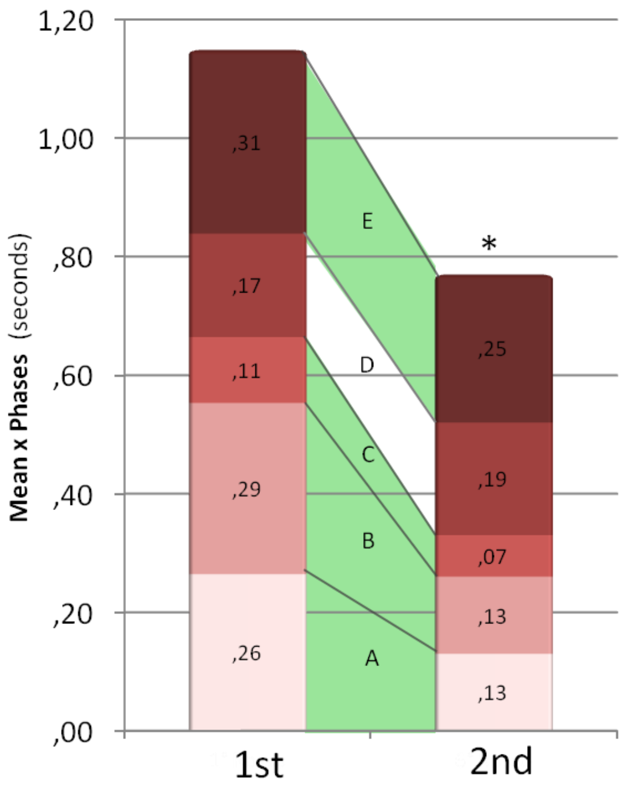


Figure 29. Learning effect. Phases of the reaction times to the 1st stimuli and the same stimuli presented for the second time inside the randomized sequence.

field, that would have been the space where the light would appear.

The learning effect that happens only for the first stimuli could then be explained by this optimization of visual attention. To demonstrate this hypothesis in the second study we will use an eye tracker too, to better track the gaze movement and explain the sequence / learning effect / open-loop response strategy that shift from only relevant areas of the visual field while driving (Lee et al., 2002).

For this particular part of the research, we have not got the opportunity to record gaze movement with a mobile eyetracker in real-life driving, as we have done in study 2 and 3.

Nevertheless it was possible to use video recordings of the experimental test, and ask to another sample to watch the video in front of an eye tracking platform. Result are not definitive, but shows that a pattern of open loop shift from the street to the warning system was present (Figure 30), as it was inferable by monitoring the gaze movement of the actual drivers in the experimental real-life driving measurement.

Figure 30. After the first stimuli drivers began to shift their gaze from the center to the street to the stimuli generator, in order to control the salient elements for this task. A perceptual learning was generated, granting a faster response in this test. But it should be questioned if this kind of visual behaviors would be as efficient in real driving condition or it would be dangerous for a safe driving, as the visual field can not be narrowed to two salient element for a safe driving.

Gender, Age and BMI

No main effect nor interaction effect with the other factors was found for Gender (t = -0.490, p = .630), Age (F = 1.761, p = .200, $\eta 2$ = .164) nor BMI (F = 1.491, p = .253, $\eta 2$ = .149).

As can be seen in figure 31 and 32, the mean response of the drivers did not divide the sample into specific clusters. With the exception of one outlier, the entire sample can be grouped in a mean interval that goes from .60 to 1.10 seconds.

As introduced in chapter 3.1. Gender and Age do affect absolute general RTs, but while driving there are others factors that mediate the results, such as driving experience. As Olson and Sivak (1986) have suggested, relatively older drivers are more practiced, more quickly recognized dangerous situations and that compensates for any slowing of perception or movement they may suffer of. These results confirm these hypotheses, as in addition, the visibility and driving condition used in this test were not critical and eventual flaws were not highlighted in this series of test.

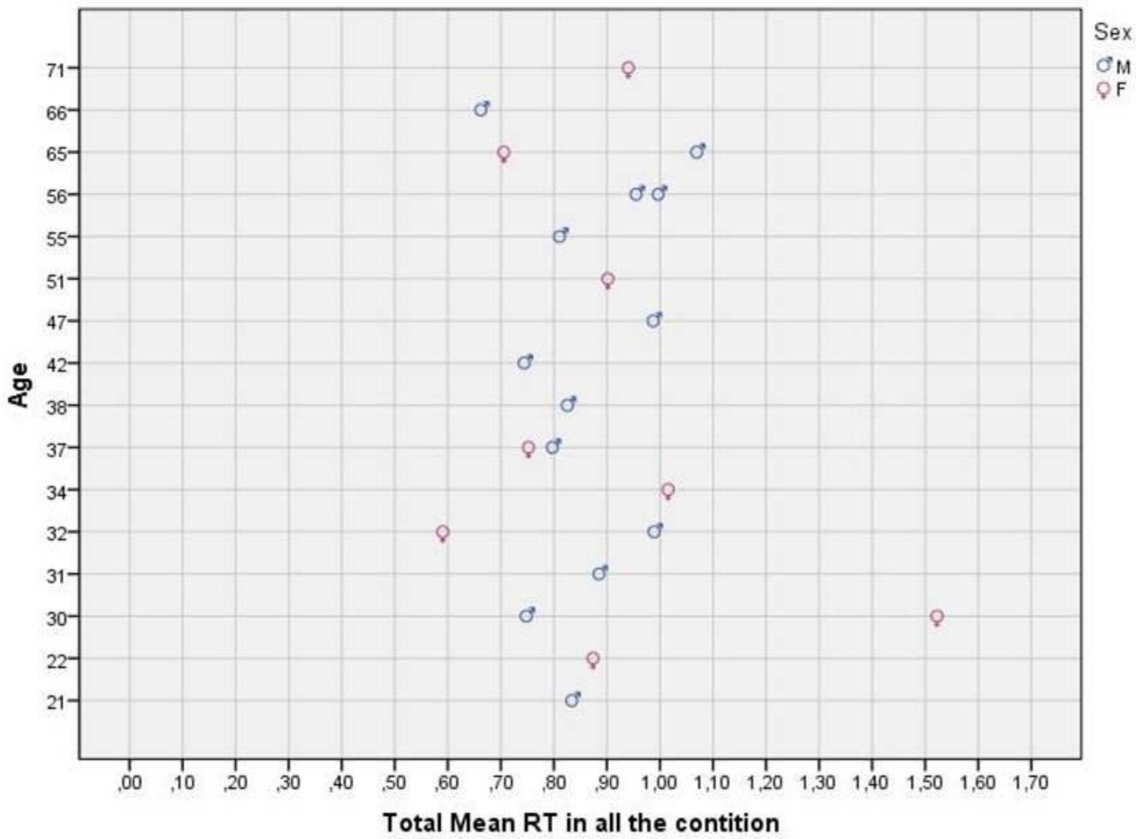


Figure 31. Distribution of total mean reaction times for all type of stimuli for Age and Gender

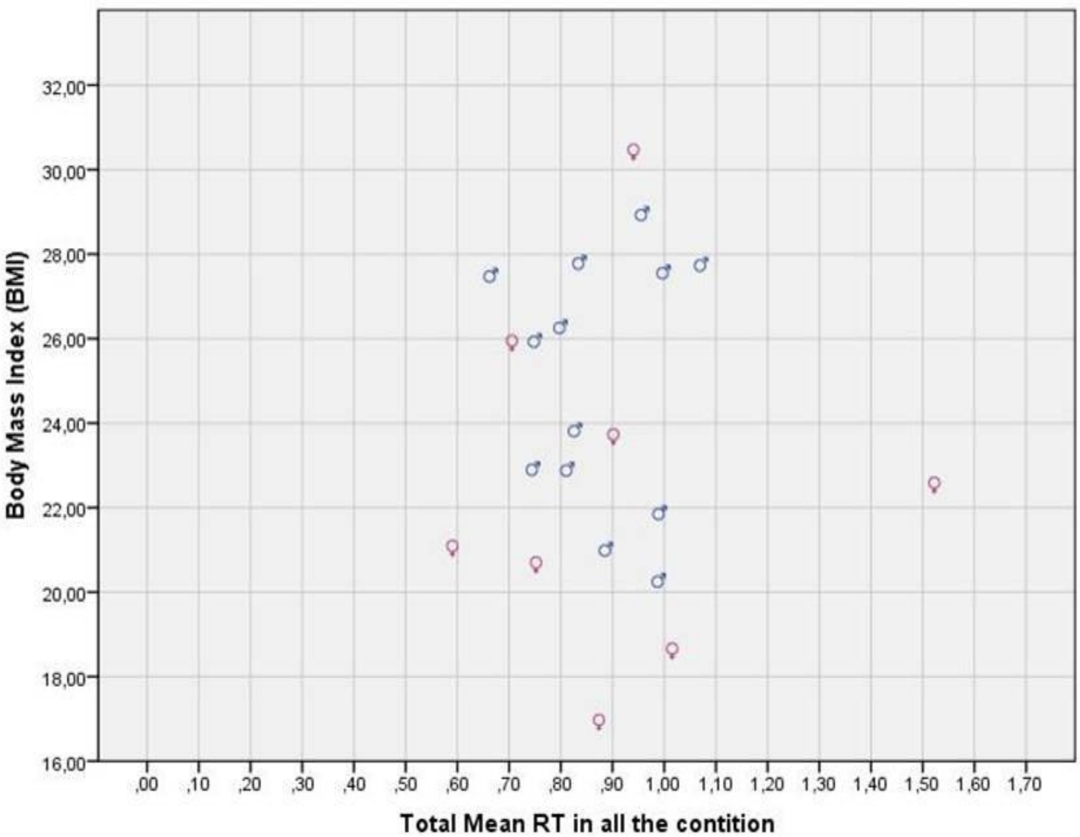


Figure 32. Distribution of total mean reaction times for all type of stimuli for BMI and Gender

3.4. Discussion

The tests performed indicate that the reaction time calculated and used in Italy results to be different from what emerges from the data and particularly inadequate to be used in a scientific way in the different areas of enquiry and practical usage. Specifically, the quantification of the aforementioned phase times needs to be completely re-evaluated, while the articulation of the phases themselves within the reaction interval must be re-formulated.

Therefore new future perspectives open up for further research to consolidate these results.

Behavior on the driving pedals is not a simple automatism: there are at least 5 steps carried out for a complete articulation of the responses in 4 distinct types of motion behavior. The reaction time process answer does not lie just on the pressure on the brake, but it is composed of phases that have their own specificity and partly serving the decision system.

Decision making process is continuous and steady. Deciding does not happen only in the beginning of the reaction interval as erroneously supposed in previous theoretical models. The influence of evaluation and decision making process related to the stimulus extends itself on the reaction times of all phases. The awareness of this possibility can avoid leaving the car to its own devices and carrying out every possibility of reaction-action until the last millisecond.

Results clearly show that the variation in reaction times apply mainly to the decision making phases (A-B) and not to motor execution phases of letting off gas (C-D) or pressure on the brake (E).

Variation of times depending on expectation are all determined by perception and evaluation of the situation by the subject, and are influenced coherently as psychological factors regulating perception, attention, emotional regulation and decision making vary.

It could be interesting to examine in depth in which way some conditions may slow down reactions while driving (internal and external distracters, e. g. use of mobile phone, cognitive fatigue, tiredness) or in which way different categories of more realistic signals or environmental stimuli may interact with subjects' expectations to the aim of improving driving responses during the crucial phases of decision making and reactions to road situations.

In particular, to try and answer to questions of this kind, we wanted to begin from the research on the real car in the attempt to consider it as an actual reference in the real world to start from for our enquiry towards the virtual one.

Data from the first study will be used as a reference database on which virtual simulators will be tested to understand how adherent to reality will be the responses obtained in virtual driving, with respect to the real one.

Putting up a methodology for this kind of comparison is complex and we should use methodological precautions enabling us to control variables and experimental setting, but if correctly achieved they will allow to evaluate the goodness of a virtual reconstruction using experimental data, quantifying the ecological validity of the results and making or not possible, as a whole or with some specific correctors, the generalization of what is going to be measured on a simulator with respect to reality.

If we know the levels of applicability to reality of a simulated test, once been tested it could be used to create trainings of which we know the limits and the potential positive side-effects that it could have on reality.

For example, if we built a test identical to the one created in the first study, but carried out in a virtual environment entirely, and we went to measure with the same methodology, the same instrumentation and the same ratio, then we could have two analogous databases to confront. If this confrontation would show any statistical adherence to the real results, it could be concluded that that virtual instrument has some potential to be used as an "experimental" place where to try and test possible trainings and measuring their side-effects on reality in the future.

With our second experimental study we tried to test and quantify the goodness of a virtual setting with an equal experimental task, relating it to real one.

The possibility of using externally validated simulation will also allow using the specific potential of virtual environments and a more controlled laboratory setting, in order to be able to test how the dynamics showed in the RTs can adapt, evolve and be modified within diverse and different conditions. This will enable us to detect also other laboratory parameters to describe the reaction time process better

Finally, with the third experimental study we will try and translate the manipulations of expectations in a context not practically realizable, such as the study of pedestrian crossing and collision, in a context of urban driving with traffic.

The results of this path will yield a more profound and complete knowledge of the phenomena determining variation of driving response to hazard, and at the same time could also give validated hint on the actual level of generalization of a virtual simulation.

Chapter 4
Study 2

Decision Making Task in Virtual vs. Real Driving

Measuring the Influence of Driving in a Simulation on RTs

4.1. Introduction

As emerged from results of Study #1 the role of expectations and perception of danger is crucial in affecting perception, attention and decision making process while reacting to a driving danger.

Moreover the fact that neither age, driving experience, gender nor BMI influenced the responses in the different conditions, underline once more the importance of drivers' attentional and decisional process, for fostering appropriate and faster reactions in emergency situations.

These results encourage the deepening research on the mental experience of the driver in these critical situations.

This study will address the role of psychological factors on RTs with two main focuses:

I. Situational awareness, attention, stimuli elaboration and cognition can be measured not only by indirect measures like RTs, but also directly thru specific focus on eye movements, heart rate activation and other physiological parameters. With this study we are interested in using these indexes to better articulate the exploration of the influence of the manipulation of driving conditions on RTs and expectations.

II. We are interested in investigate the reaction times in a particular situation that is the one elicited in a virtual driving simulator. Use of virtual simulations allows to measure and create different aspects of the RTs task that in real-life driving could not be measured or faced. The interests are to understand if those tools can be used with

To fulfill these objectives we will repeat the experiment carried out in study 1, but in a virtual situation, measuring three main targets: gaze movements, physiological activation and comparison of absolute and relative RTs.

Gaze Movement and RTs

Examine in depth the role of driver situation awareness, risk perception and expectations on reaction times, as that these elements are particularly stressed in artificial context. Visual attention and risk perception, are among the main causes of road accidents (Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006; Lee, 2008; Reyes & Lee, 2008, Summala, 1996; Vorderer & Klimmt, 2006) and can be studied by analyzing eye movement and gaze fixations (Ciceri & Ruscio, 2014; Endsley, 1995; Konstantopoulos, Chapman, & Crundall, 2012; Martens, 2004). Evidence shows that an exploration of the visual field can be organized to alter drivers' gaze orientation and configuration of saccades and fixations around salient points to enable safe driving (Crundall, Underwood, & Chapman, 1999).

A more systematical analysis of attention and eye movement using an eyetraking system during the driving sessions could provide further information on GRT, as well as provide more data about responses in peripheral view. Using an eye tracking software we will measure the saccades behaviors, quantify time to first fixation of the gaze since the appearance of the different stimuli. Gaze movement throughout the whole task will be also monitored to gain different information about the visual field while driving.

Heart Rate Variability and Executive Functions

A more systematical analysis of psychological activation during the RTs task could help in better understand the role of decision making process and emotional evaluation of the driving situations, in particularly critical condition that is the fast response to potential hazard vs. normal driving.

One interesting feature that can be found in literature and RTs regards Heart rate variability (HRV). The faster the reaction time, the smaller the HRV, suggesting that higher sympathetic modulation is related to faster responses.

HRV has been studied as an important marker of autonomic nervous system (ANS) modulation (Achen and Jeukendrup, 2003; Pagani et al., 1997; Park et al., 2007; Sandercock, 2007). The ANS is composed of two systems: the sympathetic nervous system (SNS) and the parasympathetic nervous system (PNS) (Thayer and Brosschot, 2005; Thayer and Lane, 2009). In order to function efficiently in complex response as driving, is requested a dynamic interplay between SNS and PNS, that is mediated by the prefrontal cortex (PFC) that is involved in the activation and inhibition of SNS and PNS activity during executive and cognitive tasks (Friedman, 2007; Thayer and Brosschot, 2005; Thayer and Lane, 2009). Specific cognitive domains that are sensitive to PFC activity include executive functions, selective attention and affective responses (Thayer and Lane, 2000). To measure the attenuation of SNS and increasing PNS activity, HRV is used. In particular high HRV, and more specifically the Heart Frequency and time domain measures are associated with higher PFC activity (Lane et al., 2009). That is to say that HRV reduces as attentional demand increases: the more demanding tasks the lower the standard deviation of all NN intervals (SDNN) and the square root of the mean of the sum of squares of differences between adjacent NN intervals (rMSSDs) (Backs et al., 1994; Luft, Takase, & Darby, 2009, Porges, 1972; Porges and Raskin, 1969).

Heart Rate Variability and physiological activations of the driver during the test will be recorded, to better describe the effects found in study 1, and introduce more complete contextualization f the role of human factor in RTs.

As it was not possible for us to record HR in real-life driving, so for the comparison of real vs. virtual driving during RTs, we will base our result on the one reported in literature: Li, Zhao, Xu, Ma, & Rong (2013) reported a heart rate of 75,7bpm in a virtual environment vs. heart rate 81,3bpm in real-life driving, without surprise events to react to. While another experiment real-life driving found that during nominal driving, mean HR was 77.46 bpm (*SD* = 3.6) and increased as a function of the additional task demand: 80.91 bpm (*SD* = 3.3) during the radio listening condition, 82.72 bpm (*SD* = 3.5) during the conversation with the passenger and 83.75 bpm (*SD* = 2.3) during the phone conversation (Collet, C., Clarion, a, Morel, M., Chapon, a, & Petit, C. (2009). We will use these values as references.

Moreover to better control the effect emotional activation and executive functions, a particular repetition task will be set up, to help in weight the role of sequence and cognitive load of the experimental task carried out in these two studies. In particular a repetition task will be used not for recording RTs, but to evaluate how the presence of a cognitive load and the familiarity with the task impact on the prefrontal cortex activity, thus on the attention and decision making process that lead to learning and faster of RTs.

After the virtual rendition of the task of the first study, drivers will be divided in two experimental groups in which they had to repeat the same test in two different conditions:

a. Fixed Speed Repetition with cruise control: Drivers had to repeat the task without having to control speed, that was automatically kept fixed at 50 Km/h (no cognitive load condition)
b. Keep a Fixed Speed Repetition, without cruise control: Drivers had to repeat the task and also minding speed limits, keeping a fixed and constant speed of 50 Km/h for the entire task (cognitive load condition).

This addition will be used to test two effects: the effect of speed and distraction of other road user in brake response time and weight the role of cognitive load on this kind of task, and to the effect of cognitive loads coming from perception of speed in virtual context.

Comparing Reaction Times

To quantify whether and under what extent drivers' behaviors in a virtual experience are comparable to their behaviors in real driving, a statistical analysis of the time will be carried out. We will use our specific task to compare the two setting, and use the real driving database as comparison stone to validate the accuracy of the virtual experience in reaction times. A virtual simulation validated can be used in training knowing that it would be possible to use this specific task in order to train specifically perception, attention and decision making process, that are crucial in reaction to danger.

To Build such a comparison would be complex and the results may suffer the influence of numerous variables, so an articulate research plan is required in order to be sure that results will have proper content and face validity. Moreover there are specific question that cannot be addressed in real-life test that require a lab setting or a virtual environment to be analyzed.

One of the limitations of the first study was a controlled but yet manual management of the stimuli. Using a driving simulator could provide us with standard and temporally perfectly managed stimuli appearance. Repeating the experiment controlling also this aspect would supply to eventual limitations of first study. Moreover some staring behaviors to avoid the surprise foam rubber cube appeared in the first study, but were not systematically decoded. It might be hypothesized by Green (2000) that people who are the slowest barkers have learned to avoid the obstacle by steering, or drivers were considering alternative responses and that slowed the RTs. There is no evidence whether either of these hypotheses is true, but a more systematic attention to the steering behaviors and facial expression / heart rate activation could introduce some data to support or corroborate these hypotheses.

For these reasons we decided to use the same identical task, measure the same variables plus visual attention, facial expression and heart rate variability, with the same instrumentations, with a statistical comparable sample but in a virtual setting, instead inside a real car.

The comparison will be carried out for Absolute Validity, that is the numerical correspondence between behavior in the driving simulator and real time situation, as well as for Relative Validity refers to the correspondence between effects of different variations in driving situation (Godley, Triggs & Fildes, 2002). It is considered that when it fulfills the relative validation criteria, then a driving simulator can be used as an appropriate tool in driving behavior studies (Tornros, 1998).

As a comparison between two samples is particularly critical the Barratt Impulsiveness Scale (BIS-11; Patton et al., 1995) will be used along the other

measures, to assess the personality/behavioral construct of impulsiveness of drivers in order to evaluate the sample and spot eventual outliers.
BIS11 is a multi-faceted construct and is found to relate with reactions times and impulsivity. Is composed by six first-order factors: attention, motor, self-control, cognitive complexity, perseverance, and cognitive instability impulsiveness; and three second-order factors: attentional, motor, and non-planning impulsiveness.

In this first step of the study we will use a simple virtual environment, in order to cover the comparison between real driving vs. virtual driving reaction times. Then more complex virtual scenario will be tested, translating the danger in more concrete forms of danger (i.e. pedestrian and other car in a urban environment) using a full scale dynamic simulator provided by AutoSim (Norway), consisting of a full vehicle cabin (Lancia Ypsilon) installed on a 6 axes Stewart platform (Università di Firenze).

4.2. Method

Virtual setting

The open source 3D racing simulator TORCS (The Open Racing Car Simulator) was used for its accuracy in car dynamics, brake and throttle accelerator accuracy and its openness, modularity and extensibility that made it suitable in numerous researches projects, including traffic psychology researches (e.g. Haufe, Treder, Gugler, Sagebaum, Curio, Blankertz, 2011). For our purposes TORCS was programmed in order to rebuild the same real track tested in Study #1: track length, curve amplitude and features of the environment, were virtually recreated in order to re create the Rivera track used for real driving tests (Figure 33).

Thanks to the Computer Science Department of the Università degli Studi di Milano[1], the same driving test, with manipulation of different degrees of predictability of danger for the driver, was implemented in a virtual scenario. It was possible to elicit the same sequence of light appearing in front of the drivers used for study #1.

Ads for the surprise event, it was not possible to implement a moving foam rubber cube in front of the virtual driver. We decided then to suddenly let appear a car in the middle of the roadway, in front of the driving path of the driver, and two seconds ahead before the collision. As for study #1 no anticipatory information of this type of danger was mentioned to the driver.

Figure 1: Building of the virtual track, starting from the features of the real track used the real driving test. The same set of stimuli was programmed in order to obtain the same task.

[1] DI - Dipartement of Informatics - Prof. Mario Malcangi.

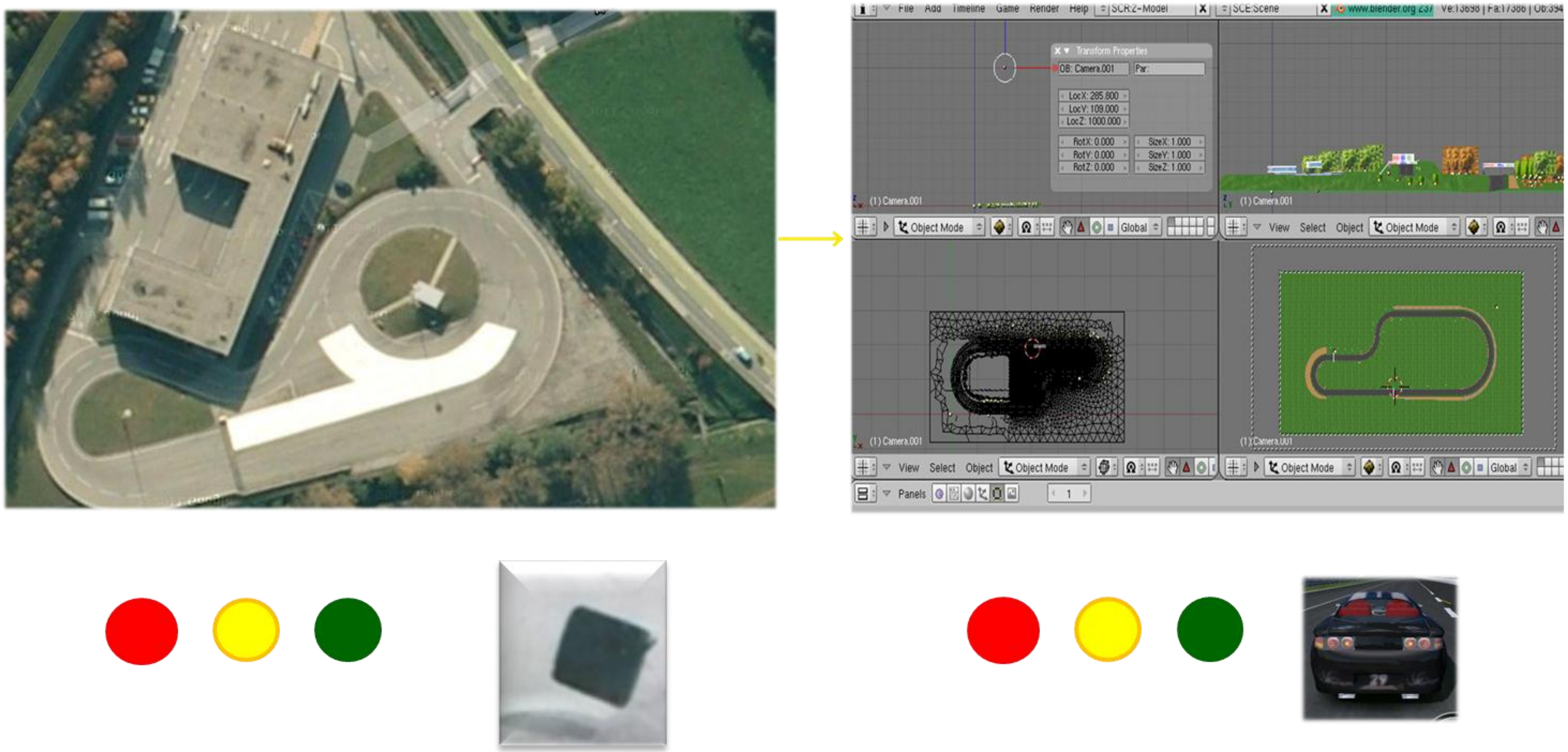


Figure 33. On the left the controlled track used in Study 1, along with the stimuli used to create the randomize sequence for manipulating the different driving situations in which record RTs. The virtual track build by Vicente Martí Centelles [martiv@qio.uji.es] respected the same turns, length and resembled the same driving environment of the track used in the first study. Then, the track was run thru the TORCS Open Source simulator, and the stimuli were added by Università degli Studi di Milano, Professor Malcangi, who implemented the possibility to program the appearance of the stimuli, and the surprise event. Unfortunately inside TORCS it was not possible to create a moving foam rubber cube as a surprise event, so it was used a car appearing suddenly in front of the driver instead.

Instruments

Sensors of the equipped car used in study #1 were moved to Laboratory setting, and installed on the static driving station of the Research Unit on Traffic Research of Università Cattolica del Sacro Cuore - Milano. The same driving setting was kept, with distance and levels of the pedals (height and distance) set up at the same values as the one used on the equipped car for real driving. In addition to the cameras and the 100/Hz sensors on the brake and accelerator pedal, driver's physiological data were collected (Heart Rate, GSR, Respiration) by BIOPAC SYSTEM MP100, Goleta, CA, and drivers' eye movement were recorded by Tobii X120 Eye Tracker (Figure 34). Manipulation of driver expectations and different situations of danger will be carried out as in study #1. A direct comparison of reaction times, drivers' behaviors and reaction in different danger condition between real and virtual driving is the main goal of this phase.

Procedure

Subject sat in the driving setting and physiological sensors were connected to the driver as well as 9-point calibration of the eyetracker for each driver.

Before starting the experimental task a neutral video was shown to the participants to record the baseline values for HR and GSR (Balzartotti et al., 2010). Synchronization of the data was granted by E-prime software.

The same instructions of Study #1 were given: Drivers have to drive on the track until they feel confident with the car, then the task would sequentially start.

As for the first study the red light meant danger, and it could be anticipated by orange-light warnings, while a green light mean no danger (cfr 3.1). Drivers have to stop at the red light as soon as they see it. After one lap on the track the first red light appeared, followed by the randomized sequence of different combinations of warning and surprise event at the end. Debriefing interview post the first session was carried out. Then the Italian version of BIS-11 scale The Barratt Impulsiveness Scale (BIS-11; Patton et al., 1995) was administered to drivers.

Figure 34. TPRCS setting: A-B) HD Cameras; C) Stimuli generator; D) U-93 sensor run of the accelerator pedal (mm, 100 Hz); E) WA-300 sensor, pressure on the brake (N, 100 Hz); F) Signal interface MX-840; H) BIOPAC SYSTEM MP100 + MindWare HRV 3.0.17, EDA 3.0.15; I) Control panel for synchronization HBM+MB; L) Tobii X120 Eye Tracker.

Sample

In order to compare results to Study #1, we decided to carefully select 21, participants among these 41, requiting volunteers with the same characteristic of age, gender and Body Mass Index (BMI = kg/(m)^2) of the 21 drivers that participated to the first experimental condition on real car driving. The procedure of building to similar samples and not the same sample (Li, J., Zhao, X., Xu, S., Ma, J., & Rong, J. 2013) was chosen to preserve the effect of expectations on the RTs and avoid side effects of sequence and learning effects.

Forty-one drivers participated to the test, (Male = 17, Female = 23; age (*M* = 37, *SD* = 15). As can be seen in Table 5 the distribution of the two sample matched, and no significant differences in the sample were found for age $F(1,21)= .003$ $p = .959$, gender $\chi^2 = .389$; $p = .533$, nor BMI $F(1,21)= .692$ $p = .410$ (Figure 35).

The sample's score for the Italian scale of Barratt Impulsiveness Scale BISS 11 for first order factors were: Attention *M* = 9.4, *SD* = 3.1; Motor *M* = 12.3, *SD* = 2.9; Self-Control *M* = 13.1, *SD* = 3.0; Cognitive Complexity *M* = 11.5, *SD* = 2.2; Perseverance *M* = 7.0, *SD* = 1.5; Cognitive Instability *M* = 6.1, *SD* = 1.5.

While second order factors were: Attention *M* = 15.7, *SD* = 2.9; Motor *M* = 19.3, *SD* = 3.4; Nonplanning M = 24.7, *SD* = 3.8.

Calculation

The responses for the first study were considered as one level of the between variable driving setting (Real driving vs. TORCS driving), in order to compare the single elements of the reaction process to danger:

A) Gaze Response Time: from appearance of the danger stimuli to the first orientation of the drivers' gaze towards the stimuli,
B) Lift from the Accelerator: from orientation of attention to the beginning of accelerator pedal decrease,
C) Completely Rise the Accelerator: time from the beginning of the decreased pressure on the accelerator, to its complete decrease
D) Movement Time: time for moving the foot from accelerator to the brake,
E) Brake Reaction: maximum pressure on the brake pedal.

The responses were related to the different level of expectation manipulated thru the same stimuli sequence used in the first study:

1R: first stimuli in the randomized sequence - red light; 2 R: red light without a warning inside the randomized sequence; 3 Y-R: two seconds orange light warning before red light; 4 G-R: deceptive information, no danger green light, before the red light; 5 C: cube/car surprise event. Reaction times for all the phases, thru all the stimuli were recorded using the same equipment of the first study. General Linear Model 2x5x4 (Experimental condition x Phases x Stimuli) was used to compare reaction times in the two conditions. In addition to measuring RTs, Harte Rate variability was calculated using Mind Ware software HRV 3.0.17. Manual observation of all interbeat interval values before analysis in order to ensure data integrity and detecting moving artifacts was performed thru the software (Figure 36). HR and Time domain parameters of heart rate variability were extracted and calculated for three different moment of the experimental session for each driver:

I. The Baseline value, that is the physiological activation levels while watching the neutral video;
II. The Normal driving level: that are the level of physiological activation while driving without the task of responding to the stimuli;
III. The Task level: that are the level of physiological activation while driving during the task of responding to the experimental sequence of stimuli

For each session HR, AVNN, SDNN and RMSSD of each driver (cfr. 4.1) were calculated, and related to the baseline in order to compare the Δ of individual values within each driver, to compare the relative differences among all the different drivers.

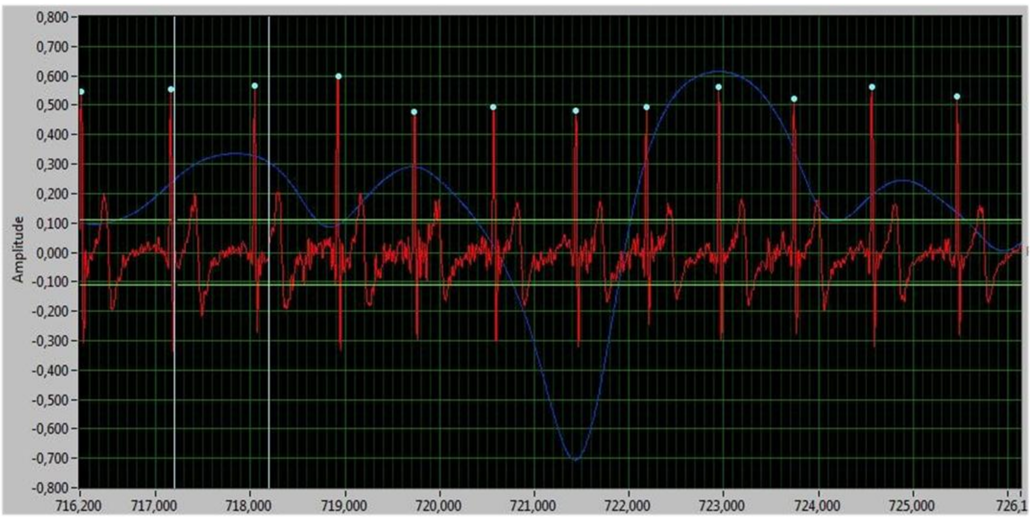


Figure 36. Harte Rate variability calculation using Mind Ware software HRV 3.0.17.

Table 5: Comparison between the two sample (Real driving vs. Virtual driving in TORCS) for age, gender and BMI.

	Gender			Age						BMI					
	Male	Female	N	< 30	30 < 50	> 50	N	M	SD	< 21	22 < 27	> 28	N	M	SD
Real	13	8	21	7	7	7	21	43.7	15.2	7	8	6	21	24.0	3.06
TORCS	11	10	21	7	7	7	21	43.4	14.8	7	6	8	21	25.0	4.03
		Total	42	14	14	14	42			14	14	14	42		

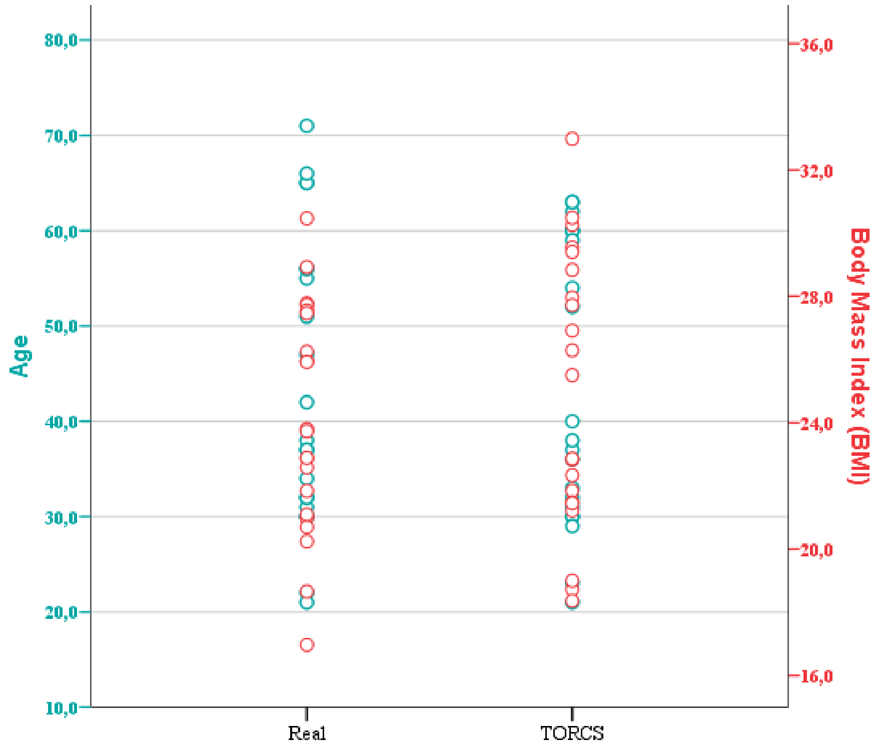


Figure 35. Distribution of the samples' features by Age and BMI. No statistical differences emerged when comparing in the distribution for age $F(1,21) = .003$ $p = .959$, gender $\chi 2 = .389$; $p = .533$, nor BMI $F(1,21) = .692$ $p = .410$.

4.3. Results

Gaze Response Time and Peripheral view

Using the Tobii eye tracker it was possible to quantify the situation where drivers' gaze remained fixed in the center of the roadway monitoring the road scene, and yet they were able to detect the appearance of the stimuli and press on the brake (Peripheral view).

When facing the first stimuli only two drivers (4.8%) detected the light using peripheral view, while all the other drivers (95.2%) oriented the gaze toward the space where the light appeared (Figure 37). After the first stimuli, the rate of drivers that began using peripheral view to detect the stimuli is already 35.7% (Figure 38). This learning does not occur for the totality of the drivers, and it remain almost constant at 38.1% of drivers after the fourth stimuli. Drivers that have learned to perceive the stimuli with peripheral view and begin the action on the pedals (LA, RA and BR) while still controlling the center of the roadway (Figure X). This learning reduce the overall RTs as we will see further. The 38.1% of drivers that use peripheral view are 6 young drivers (20-35) and 10 experienced drivers (35+).

Peripheral view and Facial expressions

Even when an eye tracking is informing that peripheral view is used by the driver, additional information can be obtained by facial expressions. A change in facial expression can set the point of the moment where the stimuli has reached driver's attention and become salient. As can be seen in figure 39, the visual attention towards the stimuli could have not be detected by the eyetracker in this case, but it was possible to record the correspondent of the GRT using the frame in which the driver changed her facial expression, moving the Orbicularis Oris (A.U. 24) muscle to press and lips before starting the reaction on the brake pedal. The facial expression developed during the process and become complete (A.U. 23) only after the press on the brake, but its beginning was set before any action on the pedals was recordable.

1st Stimuli

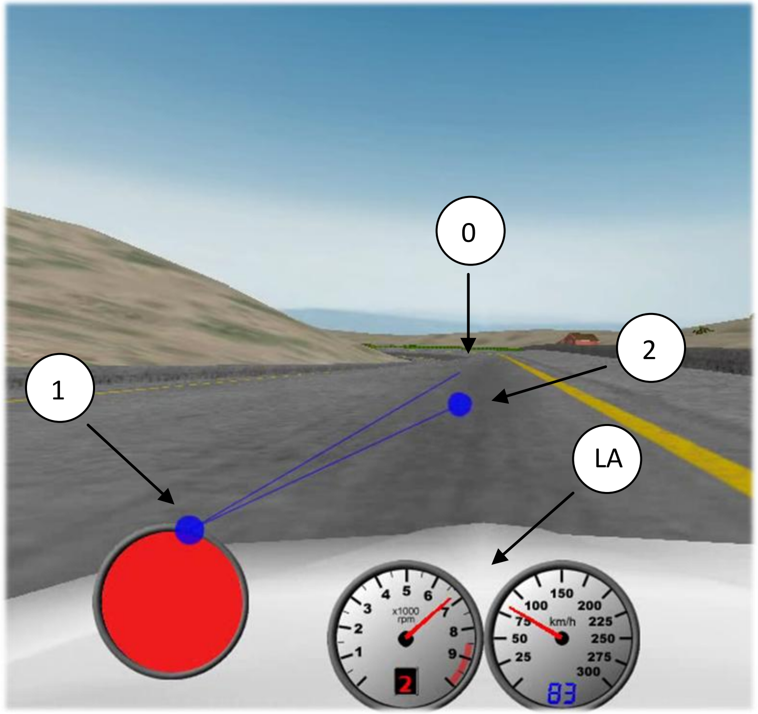


Figure 37. Gaze Response Time: Gaze shift from the center of the roadway (t_0) to the space where the light appeared (GRT t_1) before beginning the action on the pedals (Lift the Accelerator), and controlling the center of the roadway (t_2) to perform the brake reaction.

2nd Stimuli

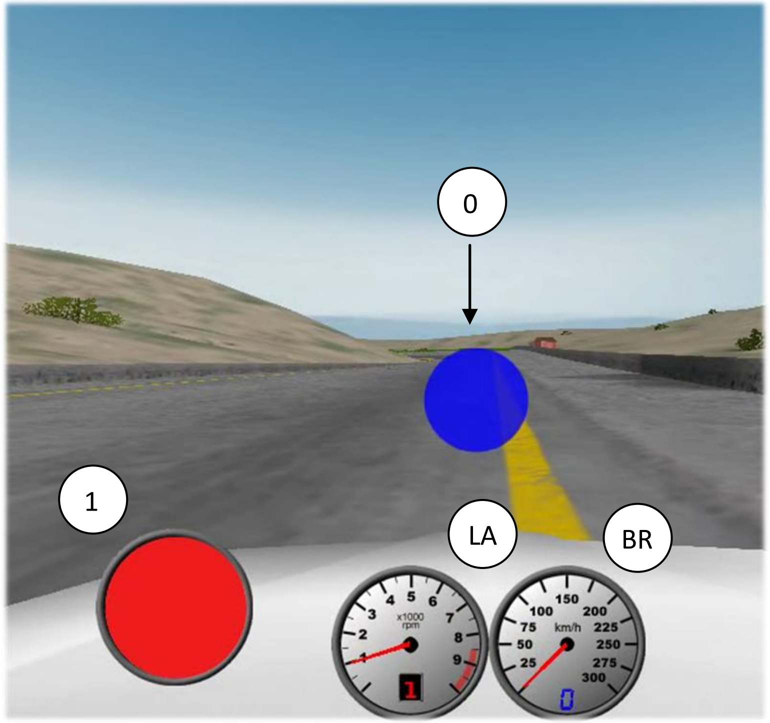


Figure 38. Learning Effect and Gaze Response Time: The driver does not need to orientate his/her visual attention from the center of the roadway (t_0) to the space where the light appeared (GRT t_1). Drivers have learned to perceive the stimuli with peripheral view and can begin the action on the pedals (LA, RA and BR) while still controlling the center of the roadway. This learning reduce the overall RTs.

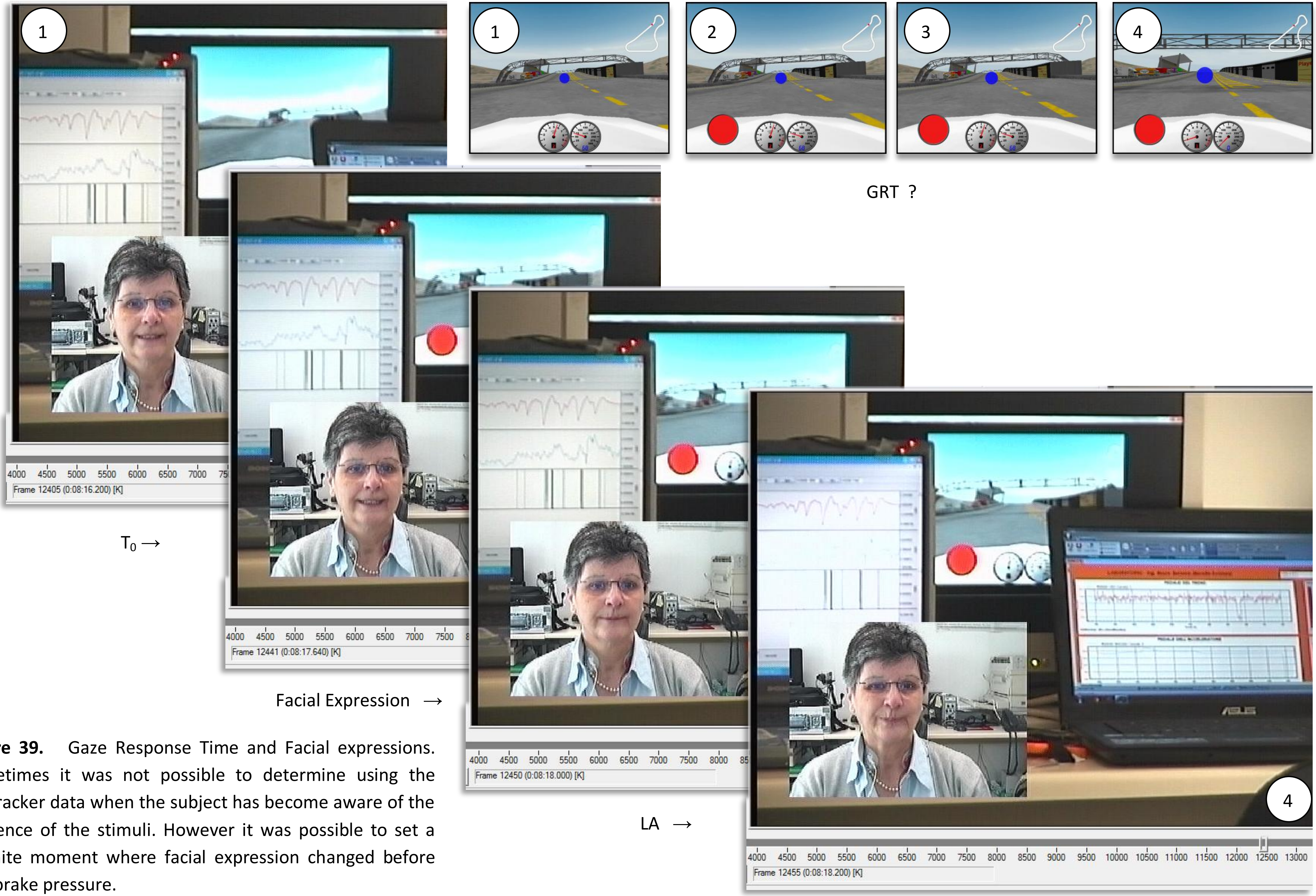


Figure 39. Gaze Response Time and Facial expressions. Sometimes it was not possible to determine using the eyetracker data when the subject has become aware of the presence of the stimuli. However it was possible to set a definite moment where facial expression changed before any brake pressure.

Heart Rate Variability

As can be seen in Table 6, the mean HR for the whole sample during normal virtual driving was 81.9 (*SD* = 11.3) bpm, decreasing to 79.8 (*SD* = 10.7) during the driving with the experimental task. The differences for the main effect type of driving were statistically significant $F(2,25) = 12.157$, $p < .000$, $\eta^2 = .537$.

To control the effect of time sequence of the task, a repetition of the test in the two experimental conditions was carried out. The HR during normal driving changed to a mean of 77.8 (*SD* = 11.5) bpm while driving without having to care about speed (free condition), vs. a mean of 83.2 (*SD* = 11.2) for the condition with cognitive load; On the contrary it decreased during the task driving to a mean of 75.3 (*SD* = 11.3) bpm while driving without having to care about speed (free condition), vs. a mean of 81.7 (*SD* = 9.2) for the condition with cognitive load. The interaction effect differences type of driving x experimental conditions were statistically significant $F(2,25) = 4.312$, $p = .019$, $\eta^2 = .158$.

A decreasing trend of the physiological activation is visible thru time, reporting that the activation requested for virtual driving with and without the RTs task (Figure 40). This effect is visible even in the cognitive load repetition, with values that after an initial (and higher) peak, tends to decrease, even if remaining at higher levels then without the cognitive load, as visible in Figure 41. These results go along with what found about peripheral view and learning effect on the response.

Considering an alternate measure for HRV, the *Average of all NN intervals (AVNN),* results were significant in the same way, as for main effect Type of driving $F(2,25) = 28.256$, $p < .000$, $\eta^2 = .551$ as well as the interaction with the experimental conditions $F(2,25) = 3.485$, $p = .039$, $\eta^2 = .132$.

The same effects are significant for the *Standard deviation of NN intervals (SDNN)* but with different configuration of the variability compared to the baseline (table 7). In fact while HR and AVNN values reach a peak of activation in the normal driving condition, and then decrease during the task (indicating an accommodation of driver's activation), even in the condition with cognitive load, the SDNN distribution present two different phenomena for the repetitions (Figure 42).

After the first normal driving session we found a similar peak with a value that from 54.8 of the baseline, falls to 46.4 (22.7) [note that the lower the SDNN the higher the cognitive effort] to going consequently back at a higher value of 57.5 (22.1) during the task $F(2,25) = 3.374$, $p = .043$, $\eta^2 = .128$. But, on the contrary of HR and AVNN, during the repetition condition values of SDNN remain constant for the different type of experimental groups: steadily positive [i.e. less cognitive effort] in the free repetition, and negative [i.e. more cognitive effort] in the repetition with cognitive load. The differences in the interaction effect are more significant $F(2,25) = 4.087$, $p = .013$, $\eta^2 = .173$, as can be seen in figure 43.

Table 6. Heart Rate Variability

	Baseline		Normal Driving		Driving with Task	
Heart Rate	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
First Time	75.8	8.8	81.9	11.3	79.8	10.7
Free Repetition	73.2	11.5	77.8	11.5	75.3	11.3
Load Repetition	75.5	7.8	83.2	11.2	81.7	9.2

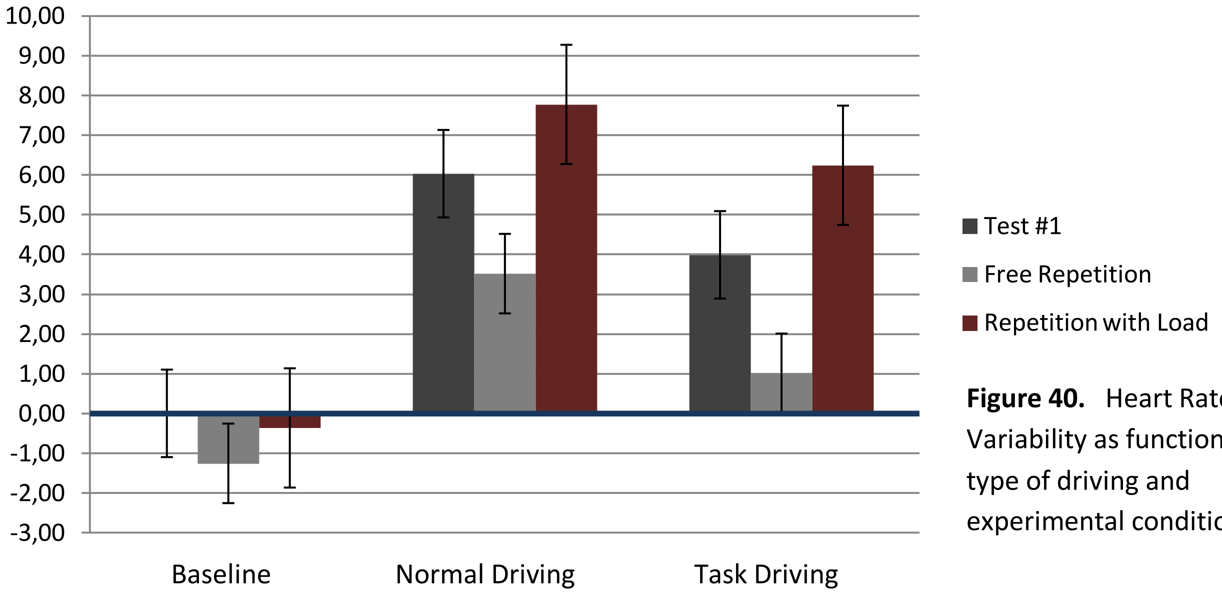


Figure 40. Heart Rate Variability as function of type of driving and experimental condition

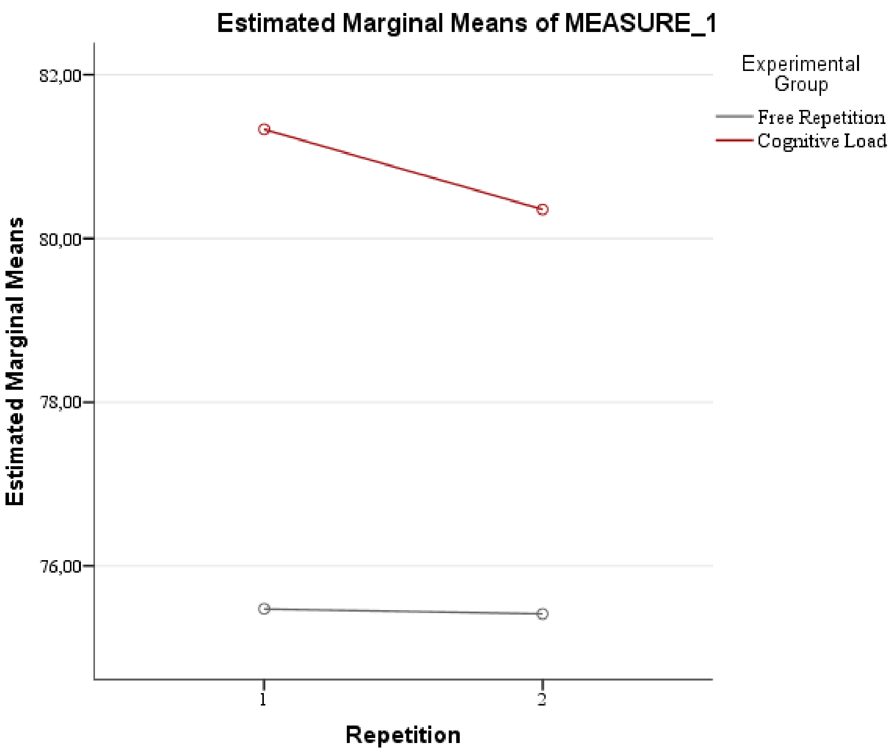


Figure 41. Heart Rate Variability as function of Task Repetition

Table 7. SDNN - NN Intervals

	Baseline		Normal Driving		Driving with Task	
Heart Rate	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
First Time	54.8	27.8	46.4	22.7	57.5	22.1
Free Repetition	47.1	14.6	54.1	23.7	54.7	27.8
Load Repetition	56.4	27.4	41.7	18.2	45.5	18.5

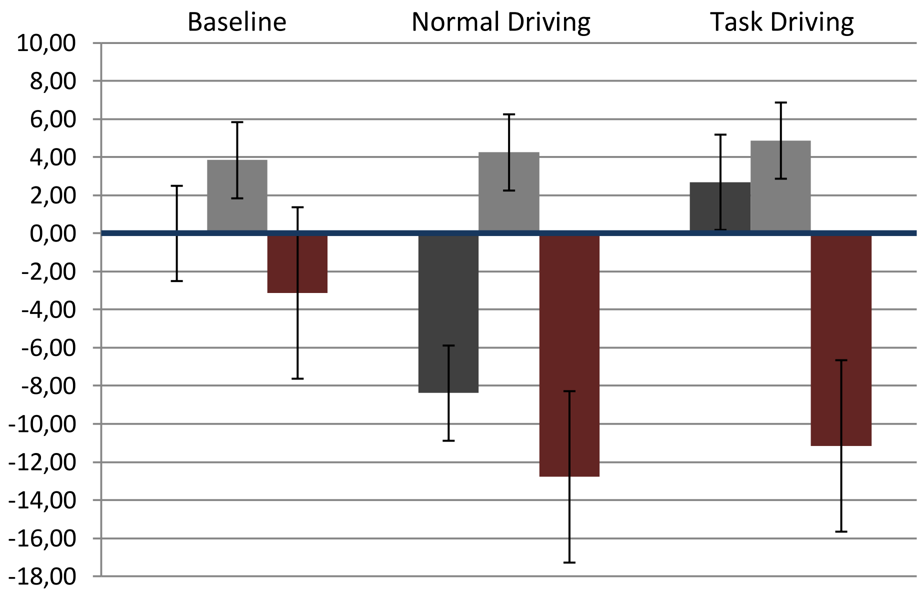


Figure 42. SDNN Variability as function of type of driving and experimental condition

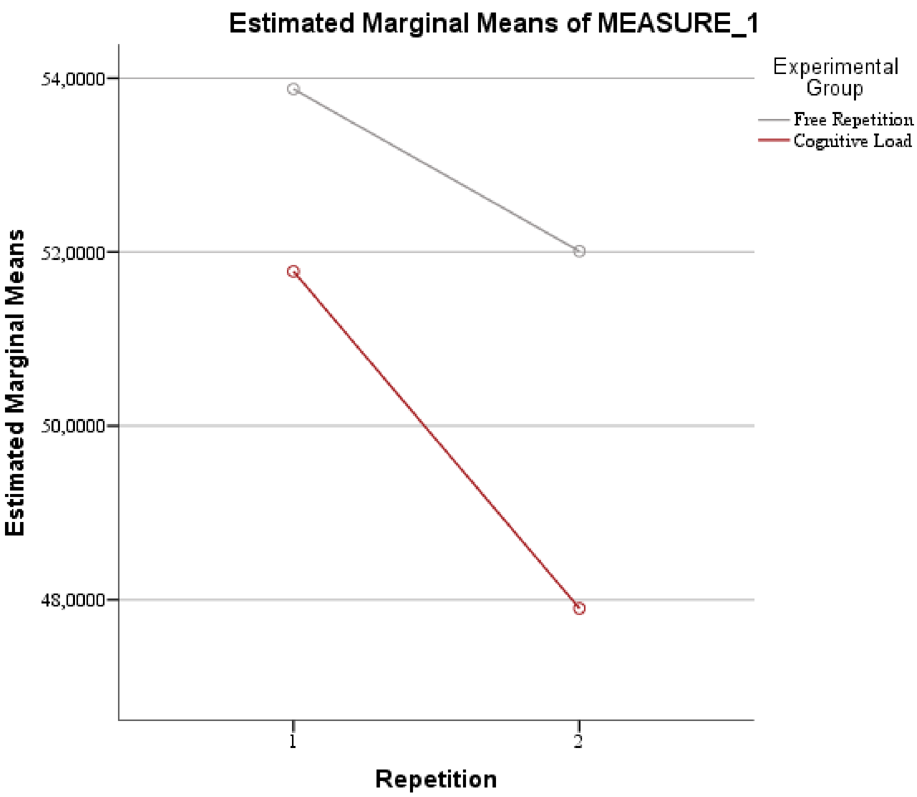


Figure 43. SDNN as function of Task Repetition

Reaction Times Comparison

1. Driving Condition

The reaction times recorded were different in the two conditions.

The main effect for experimental setting was significant F(1,42) = 52.082, $p <$ .000, η^2 = .566.

In particular the reaction times in the TORCS condition were significantly slower. The mean reaction time considering all the stimuli and summing up all the movements of the drivers till they reached maximum intensity on the brake pedal, was 1.72 seconds (SD .33) vs. 1.18 (SD .21) of the Real condition (Figure 44).

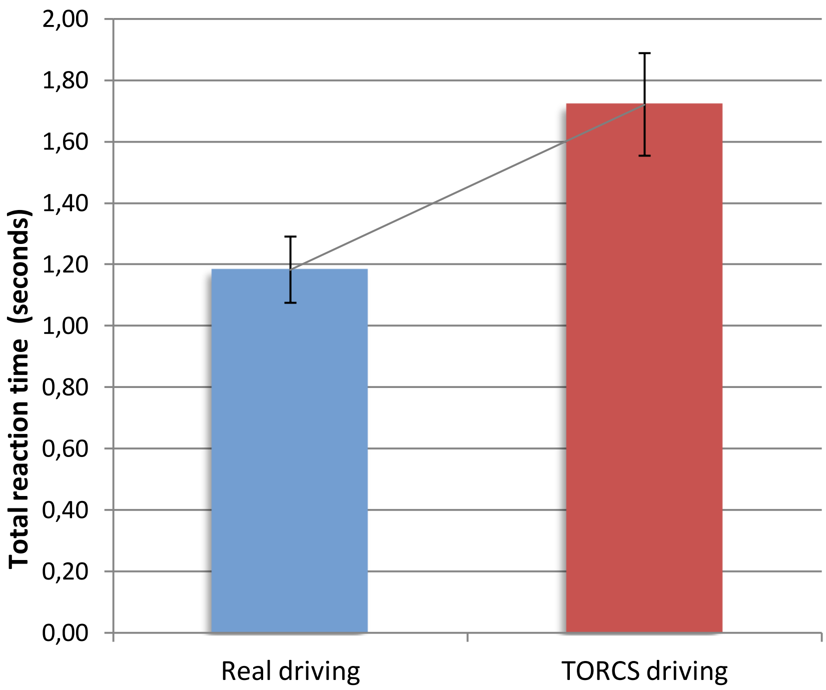


Figure 44. Total reaction times for all type of stimuli in the two experimental conditions.

Table 8. Reactions Times x Stimuli (seconds)

N = 21	Total RTs				Differential Thresholds		
Stimuli [a]	*Mean*	*SD*	*Minimum*	*Maximum*	*25%*	*50%*	*75%*
Warning	1.41	.30	.84	2.02	1.21	1.45	1.59
Expected Red	1.64	.55	.85	2.67	1.16	1.55	2.09
Misleading Warning	1.55	.42	.85	2.45	1.30	1.55	1.90
Surprise Event	1.99	.70	.93	3.83	1.67	1.77	2.27
1st Stimuli	2.19	.80	1.12	3.61	1.30	2.19	2.93

a

Different stimuli selected from the randomized sequence: 1st time the red light appear in the test; Red light shown for the second time inside the randomized sequence, Two second yellow light warning followed by red, Misleading green light before a Red light, Surprise foam rubber cube event. (cfr. chapter 3.2)

Table 9. Reactions Times x Phases (seconds)

N = 21	Total RTs				Differential Thresholds		
Phases [a]	*Mean*	*SD*	*Minimum*	*Maximum*	*25%*	*50%*	*75%*
A) GRT	.29	.14	.04	.52	.18	.28	.39
B) LA	.46	.15	.23	.77	.35	.46	.58
C) RA	.08	.02	.03	.11	.06	.08	.09
D) MT	.33	.16	.12	.66	.19	.28	.47
E) BR	.59	.22	.23	1.20	.49	.55	.70

a

A) Gaze Response Time: Time interval from the appearance of the experimental stimuli to the first shift of the driver's gaze towards the stimuli. B) Begin Lift Accelerator: Time interval from the previous phase to the first decrease on the pressure on the accelerator pedal. C) Completely Raise the Accelerator: Time interval from the first decrease on the accelerator pedal, to the complete release of the accelerator. D) Movement Time: Time interval from the last time the foot was on the accelerator to the first time a pressure on the brake start to be recorded. E) Time requested to build the pressure on the brake, until the very maximum pressure on the brake. (cfr. chapter 3.2)

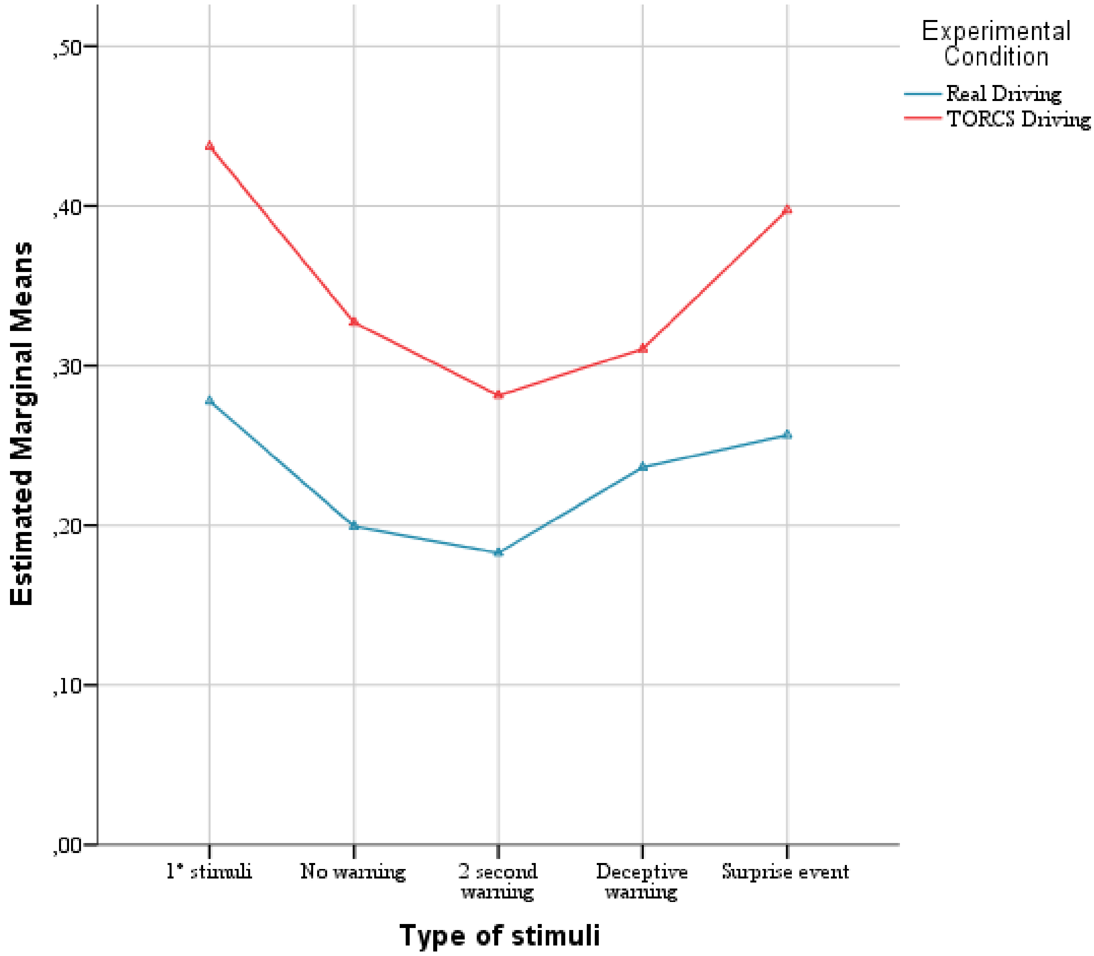


Figure 45: Type of stimuli x Experimental condition. RT in virtual condition were slower, but followed the same identical distribution of the Real driving condition for type of stimuli.

2. Type of stimuli x Setting

Even if the RT were slower, also in the TORCS condition we found the same distribution of real driving condition for reaction times as function of type of stimuli. In fact the main effect for type of stimuli was still significant $F(4,42) = 15.187$, $p < .000$, $\eta^2 = .275$, but not the interaction effect Stimuli x Experimental Condition $F(4,42) = 1.708$, $p = .151$, $\eta^2 = .041$. As can be seen in Figure 45, the same distribution of the reaction type for type of stimuli was found, suggesting that the experimental manipulation of stimuli's meanings and driver expectations on potential danger were kept the same, even in the virtual setting (Figure 46).

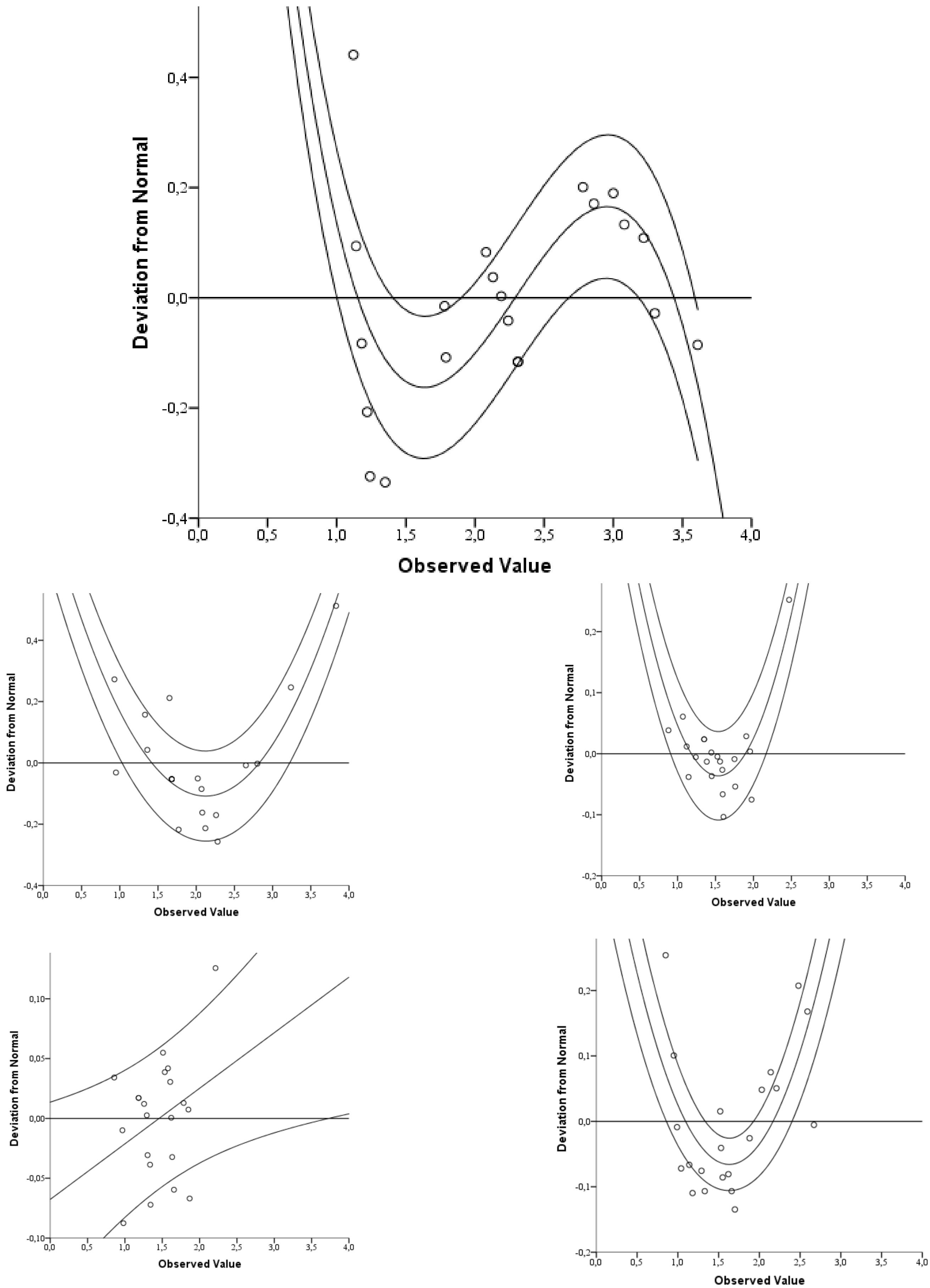


Figure 46. Distribution of Reaction Times mean values for all drivers and deviations from the Normal distribution to the different conditions: 1st stimuli (top), surprise event (top left), misleading condition (top right), two-seconds warning (bottom left) and 2nd red inside the randomized sequence (bottom right).

3. Phases x Setting

The GLM report statistical differences in the phases of the reaction process F(4,42) = 83.954, $p < .000$, $\eta^2 = .667$, as well as in the interaction of these phases with the experimental condition F(4,42) = 9.918, $p < .000$, $\eta^2 = .199$. As can be seen in Figure 47, the differences were placed in the perception phase (Phase A), in the decision making process before rising the foot from the accelerator (Phase B), and in the movement time towards the brake (Phase D).

Phase A was slower in TORCS (M = .28, SD = .13 seconds) vs. Real driving (M = .20, SD = .09 seconds) and the differences were significant F(4,42) = 4.679, $p = .037$. Drivers in virtual setting are less reactive to the appearance of stimuli in their visual field.

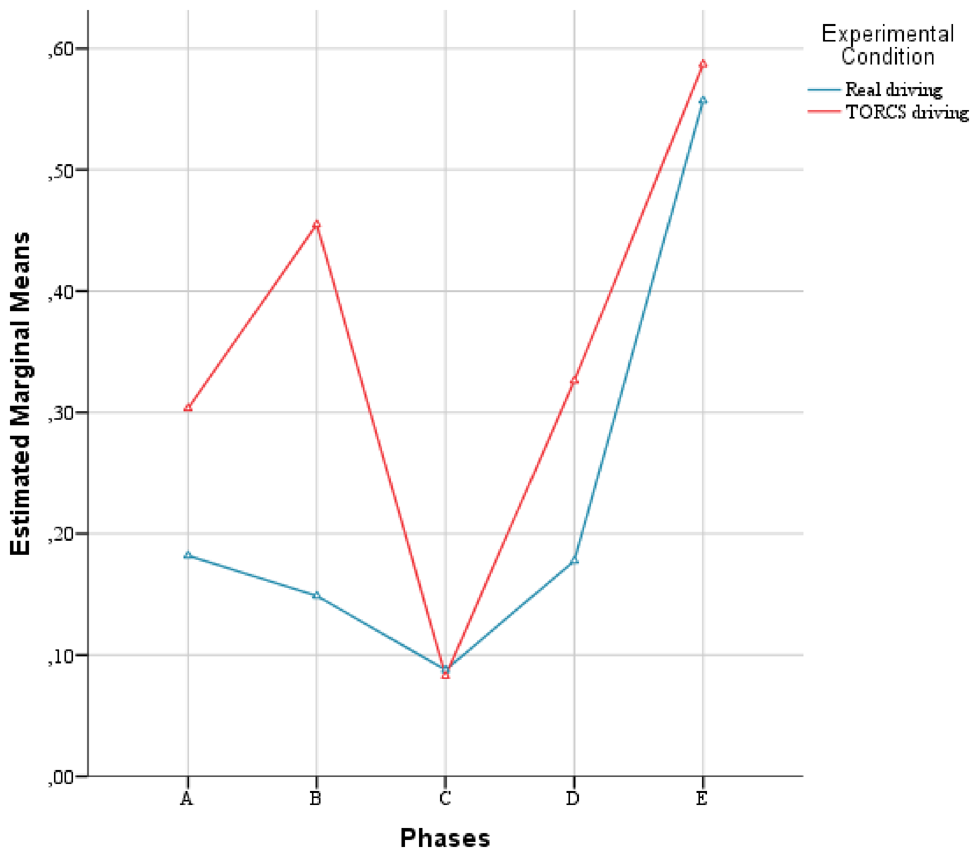


Figure 47. Phases x Experimental condition. RTs in virtual condition were slower for the perception phase A, and on the decision making phases B and D. Not in the actual motor actions on the pedals C and E.

This effect is more relevant for Phase B, that is the time needed from the moment drivers' attention is shifted towards the danger stimuli, to the moment they start rising the foot pressure on the accelerator pedal. Phase B lasted less in the real driving condition (M = .14, SD = .05 seconds) than in TORCS (M = .46, SD = .15 seconds) and the differences were statistical significant $F(4,42) = 89.717$, $p > .000$.

Phase C and E represent the actual motor execution of the foot movement on the pedals (lifting and pushing the pedals) and no differences were found between the two experimental settings.

Instead the virtual setting lead to a slower times between the rise of the accelerator, to the actual decision to move the foot towards the brake (Phase D). Phase D lasted less in the real driving condition (M = .18, SD = .06 seconds) than in TORCS (M = .32, SD = .15 seconds) and the differences were statistical significant $F(4,42) = 15.249$, $p > .000$.

4. Stimuli x Phases x Conditions

The interaction effect between Type of Stimuli and Phases was significant as it was in the first study $F(16,42) = 2.173$, $p = .016$, $\eta^2 = .052$ but it is not significant the three factor interaction Type of Stimuli x Phases x Experimental Conditions $F(16,42) = 1.604$, $p = .097$, $\eta^2 = .039$. Suggesting that once again is the type of task that interacts with the motor responses of the driver, plus an overall slowing of the reaction in the TORCS driving. In fact, as can be seen in Figure 48, the difference of the Experimental condition in interaction with the motor reaction and the stimuli is significant only for the phases that anticipate a motor response, in particular: Phase A for the first virtual stimuli $F(1,42) = 14.525$, $p < .000$; Phase B for all the stimuli in the virtual environment; and Phase D for the first virtual stimuli $F(1,42) = 4.670$, $p = .037$ and the virtual unexpected surprise event $F(1,42) = 4.991$, $p = .031$.

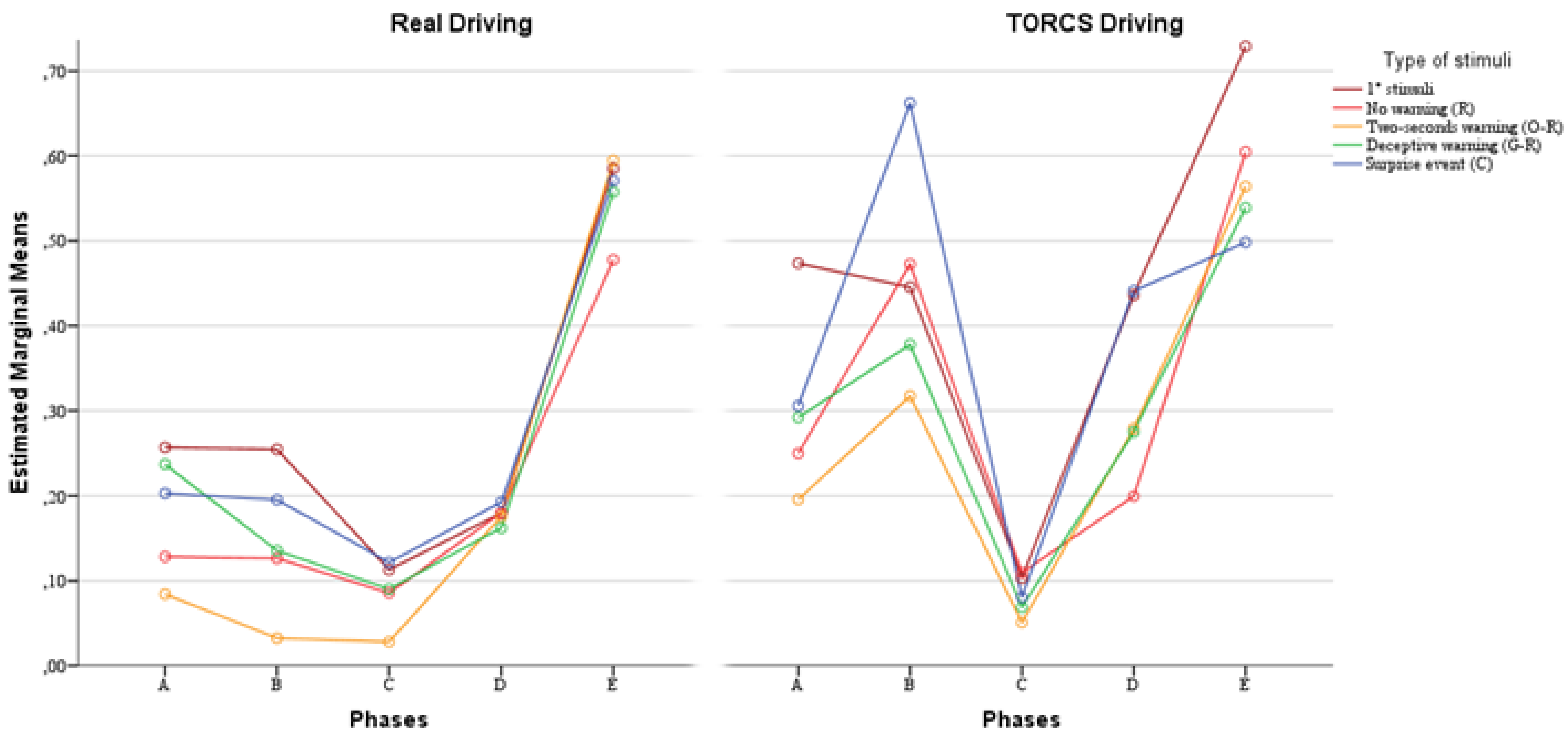


Figure 48. Phases x Stimuli x Experimental conditions. Two levels interaction effect was significant, and not the three levels interaction effect.

5. Gender, Age and BMI

No differences for age gender and BMI were found, neither in the main effect between subjects, nor in interaction with the other variables, like they were not significant in Study 1 too. This suggests that the influence on RTs might be a process independent from these factors (Figure 51).

More specifically main effect of gender was not significant F(1,42) = 2.243, p = .142, η^2 = .053, as it was not in interaction with type of stimuli F(3,42) = 0.949, p = .402, η^2 = .023, phases F(4,42) = 1.072, p = .362, η^2 = .026.

It is interesting to note that the mean reaction of males and females is exactly identical for the first phases of the RT process: perception, attention and decision making; then a slight difference can be find in the motor response on the brake, with male drivers responding faster than female drivers (Figure 49) but as said before, the differences are not statistically significant.

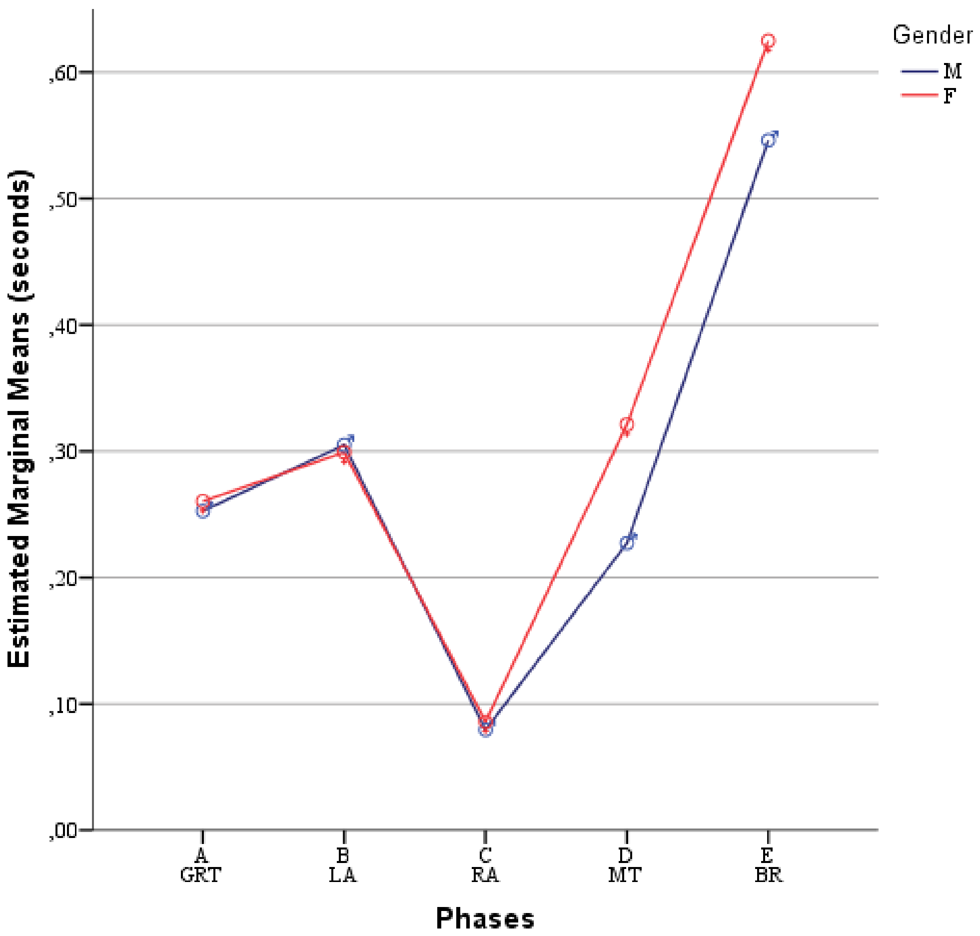


Figure 49. Differences in the distribution of the means RT in the different phases for all condition divided for Male and Female drivers. No significant differences emerged.

Age was recorded in two categories in order to split the sample in two main categories: relative younger drivers (that is <35 years old), and older drivers (i.e. >35 years old). The main effect of gender was not significant $F(1,42) = .304$, $p = .584$, $\eta^2 = .008$, as it was not significant in interaction with type of stimuli $F(3,42) = 2.101$, $p = .104$, $\eta^2 = .050$, neither with phases $F(4,42) = 1.707$, $p = .151$, $\eta^2 = .041$.

It is interesting to note that the mean reaction in the different phases of the RT process present two different trends: younger drivers are faster in perceiving and paying attention to the stimuli, while older drivers are faster in executing the motor reaction on the pedals (Figure 50). The overall differences are not statistically significant as the two differences may compensate themselves together.

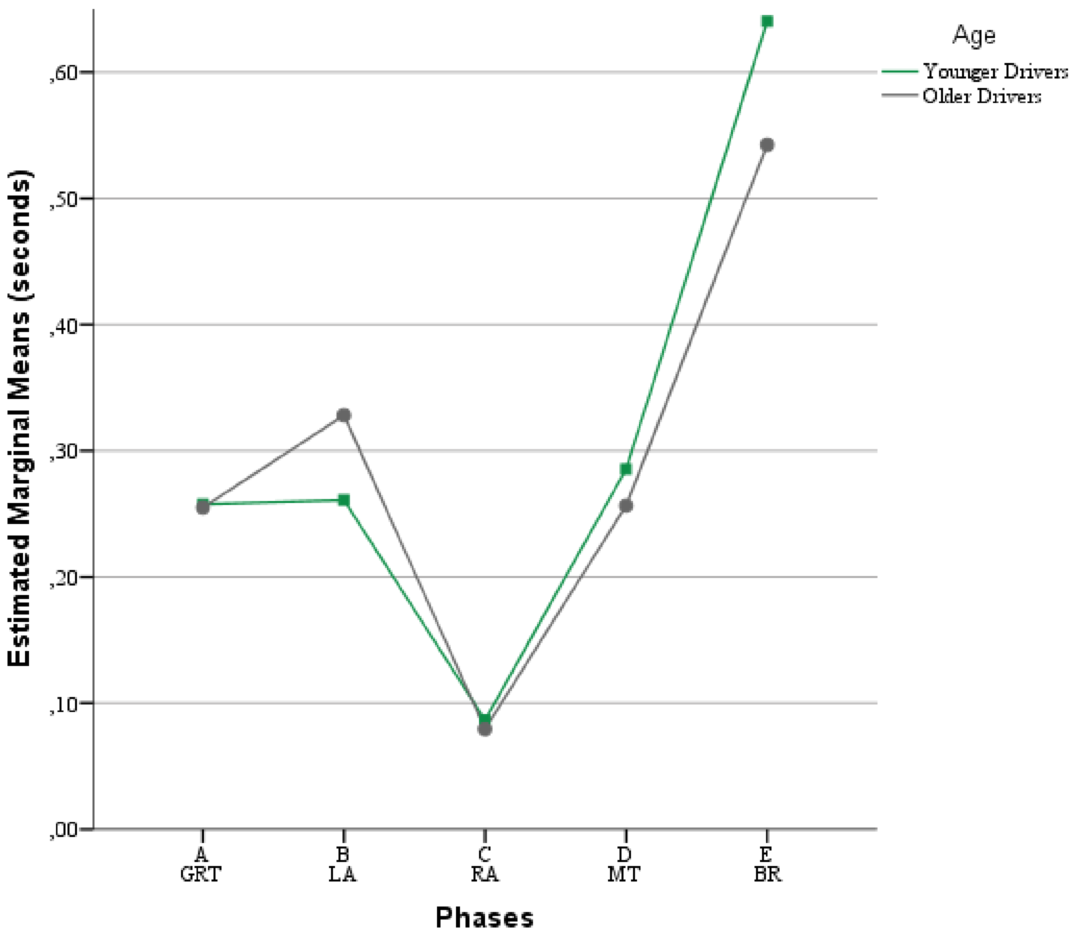


Figure 50. Differences in the distribution of the means RT in the different phases for all condition divided for younger and older drivers. No significant differences emerged.

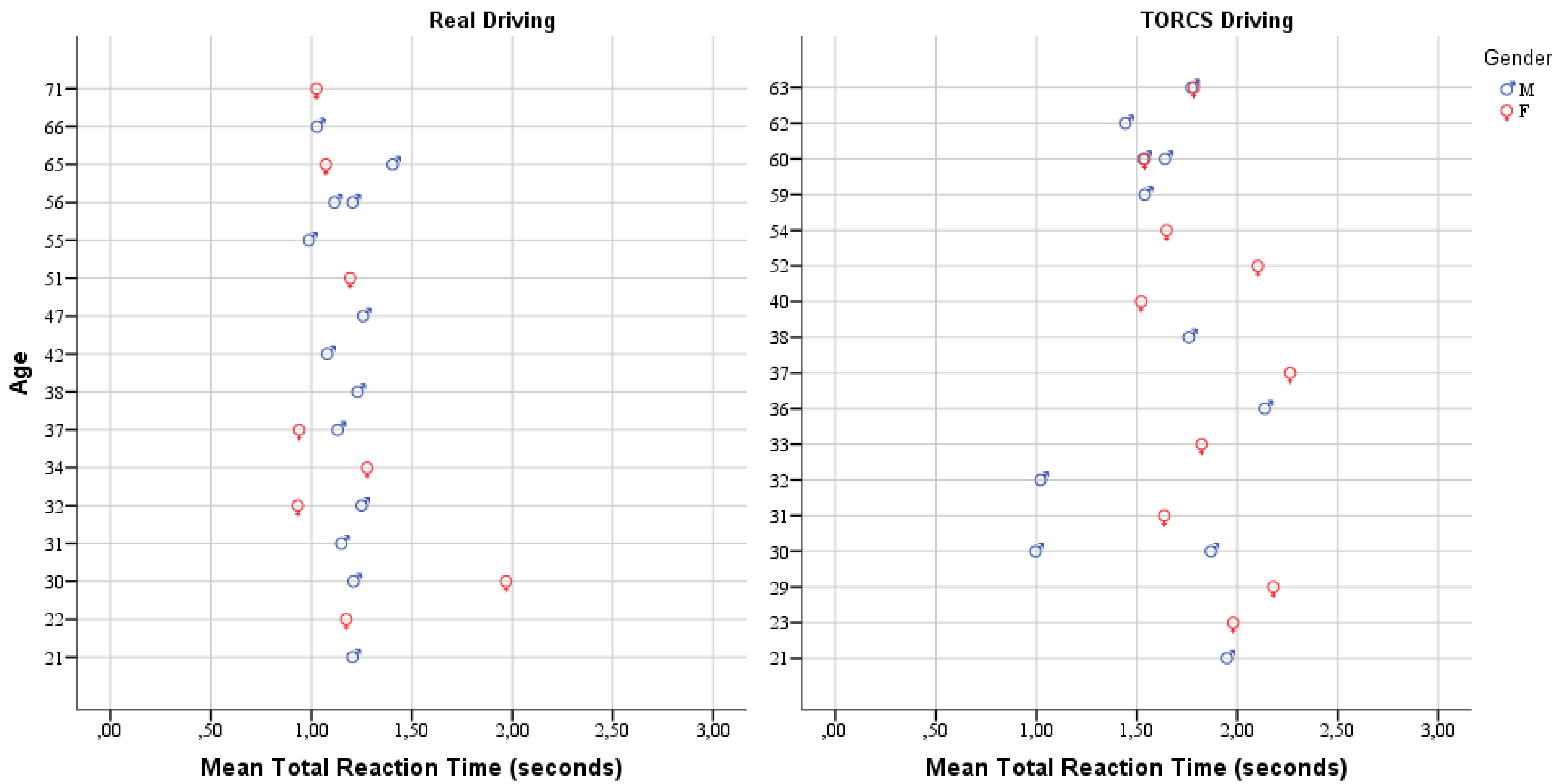


Figure 51. Means of total reaction times were slower and with a wider SD in Virtual environment, but no differences for gender, age nor BMI were found.

Surprise event

A particular focus can be done for the surprise condition. First two main differences were present for technical boundaries: first the surprise event in the TORCS condition was a car and not a foam rubber cube, that could have an impact on a faster recognition of the visual object as a car would have been more probable to appear on the roadway then an unidentified green cube object. Second the cube was moving from the left of the roadway, rolling towards the right. This comported a Gaze movement from the center of the roadway to the left (Figure 52a) in the real driving condition, while in the TORCS condition the obstacle was still in the center of the roadway (Figure 52b).

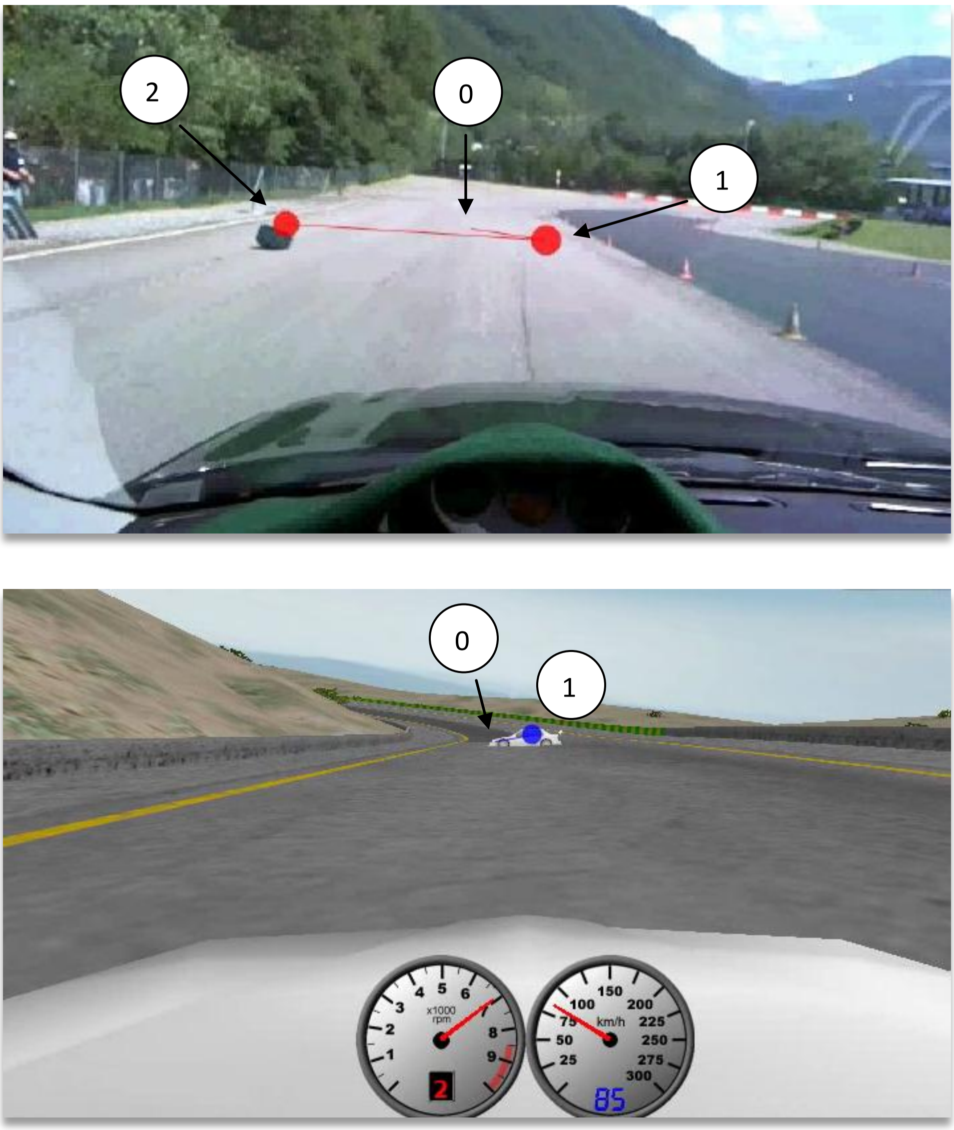


Figure 52. The surprise event in the real-life condition (a) vs. the surprise event in the TORCS driving condition (b)

Giving these two differences, two main considerations can be done:

I. The static object elicited more steering reaction than the moving object. The steering maneuver turned out to be more rapid and effective in avoiding the obstacle

II. The immediate emotional reaction to the eventual run over the surprise event were different in the real vs. virtual context

Steering behavior

Steering reaction was found only in the TORCS driving condition. Of 41 participants of the study 2, 28 (68.3%) drivers performed the steering reaction to the surprise object. Considering the sub-sample of the 21 drivers selected for the comparison with real driving, 12 (57.1%) performed the steering reaction.

As for RTs, even steering behavior can be divided in different phases:

A) Gaze Response Time: Time interval from the appearance of the stimuli to the first shift of the driver's gaze towards the stimuli.

B) Time for Steering (TS): that is the time interval from the GRT to the beginning of movement of the steering.

C) Steering Reaction Time (SRT): that is the total reaction time to perform the steering reaction.

Table 11 shows that SRT are faster than a full Brake response to the surprise event (cfr. Table 1)

Table 11. Steering Reactions Times

N = 41	RTs to the surprise Event				Differential Thresholds		
Phases [a]	*Mean*	*SD*	*Minimum*	*Maximum*	*25%*	*50%*	*75%*
A) GRT	.20	.18	.04	.52	.05	.18	.25
B st) TS	.78	.18	.27	1.17	.73	.81	.91
C st) SRT	.89	.22	.46	1.69	.77	.80	.97

[a] A) Gaze Response Time: note that these are the mean of the total drivers who participated to study 2 and not just the 21 used for the comparison. B st) Time for Steering: C st) Steering Reaction Time.

Emotional response

In the Real-life condition 6 drivers (28.6%) ran over the surprise event, and 7 drivers (33.3%) hit the surprise event in the TORCS condition, so this parameter seems to respect the relative validity once again of the virtual condition.

Analyzing the dynamics of these accidents it was possible to find slowing in the brake response phase, or even no responses on the brake at all even in TORCS driving, as it was for real-life driving (cfr 3.3).

A main difference however can be found in the emotional reactions of the drivers that hit the object and got involved in a road accident.

In the few seconds that followed the crash in real-life driving it was possible to notice some expressions that can be related to negative and unpleasant emotions unfolding during the process (cfr. 2.3 and 3.3). As can be seen in Figure 53, some early surprise configurations (e.g. A.U. 1, 2, 5, 15) become concern and worry about the accident emerge subsequently to the crash (e.g. A.U. 23, 24, 28).

On the other hand in the virtual driving condition after the early surprise facial expression (e.g. A.U. 1, 2, 5, 15) it gives space to positive facial configurations e.g. A.U. 6, 12,13 (Figure 54).

This pattern can be observed in almost all cases of run over the obstacle (except one) (Figure 55)

This qualitative analysis can maybe explain the differences of the two contexts in terms of situational awareness. Being aware that the virtual context bring no real harm consequences, may be the crucial difference that slows RTs in the virtual setting. As also the HRV analysis have underlined this less situational awareness and worry may be related to the less physiological activation of the drivers in the virtual environment.

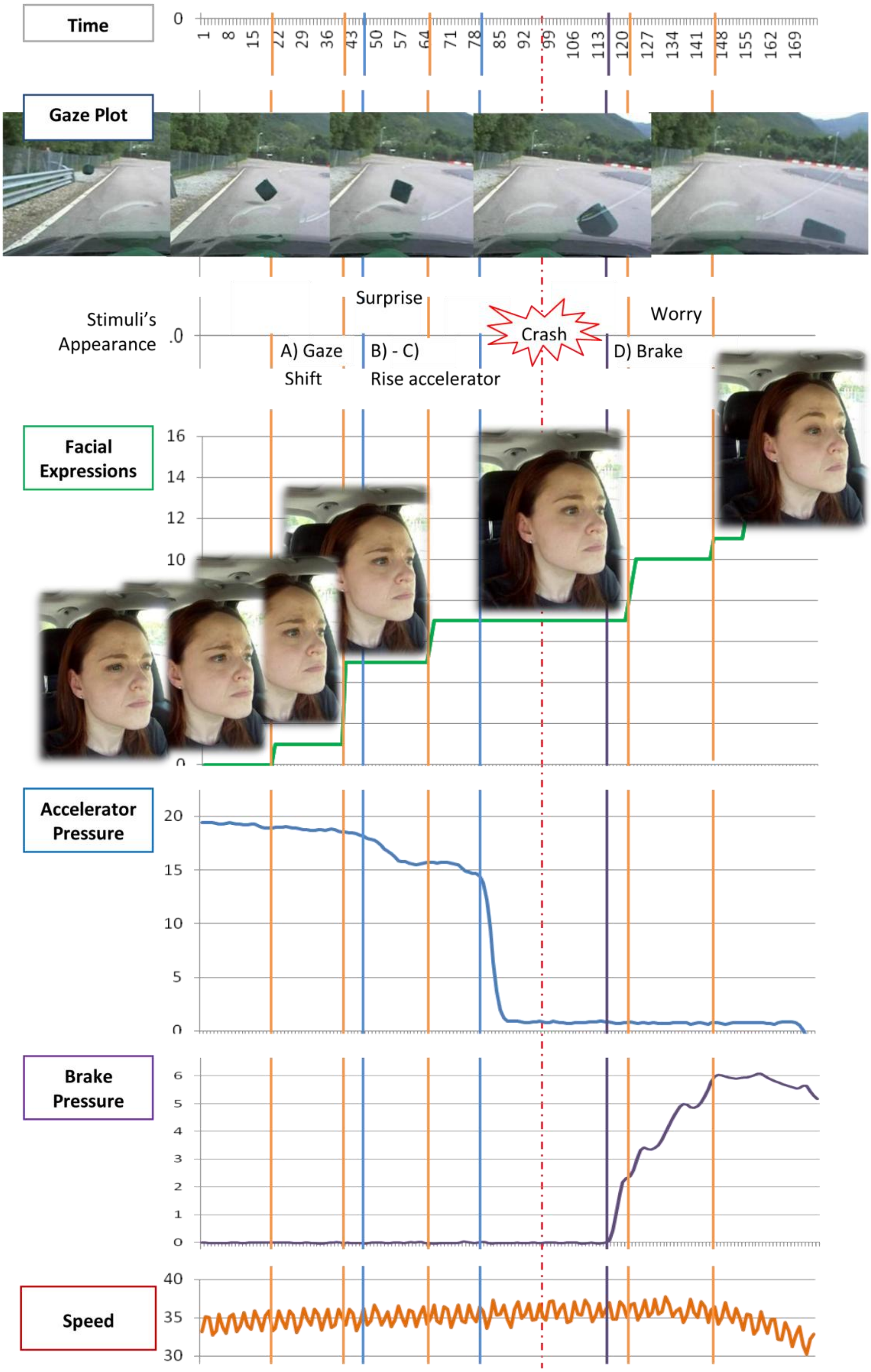


Figure 53. The driver performed no action on the brake while facing the surprise event. From facial expression analysis it is possible to evaluate that the driver actually has seen the object, and it was possible to notice some expressions that can be related to negative and unpleasant emotions unfolding during the process. Some early surprise configurations (e.g. A.U. 1, 2, 5, 15) become concern and worry about the accident emerge subsequently to the crash (e.g. A.U. 23, 24, 28). No brake is pressed while elaborating the surprise stimuli. After the crash some brake pressure is measured as well as some concern configuration on the driver's face at least in the first seconds that follow the crash.

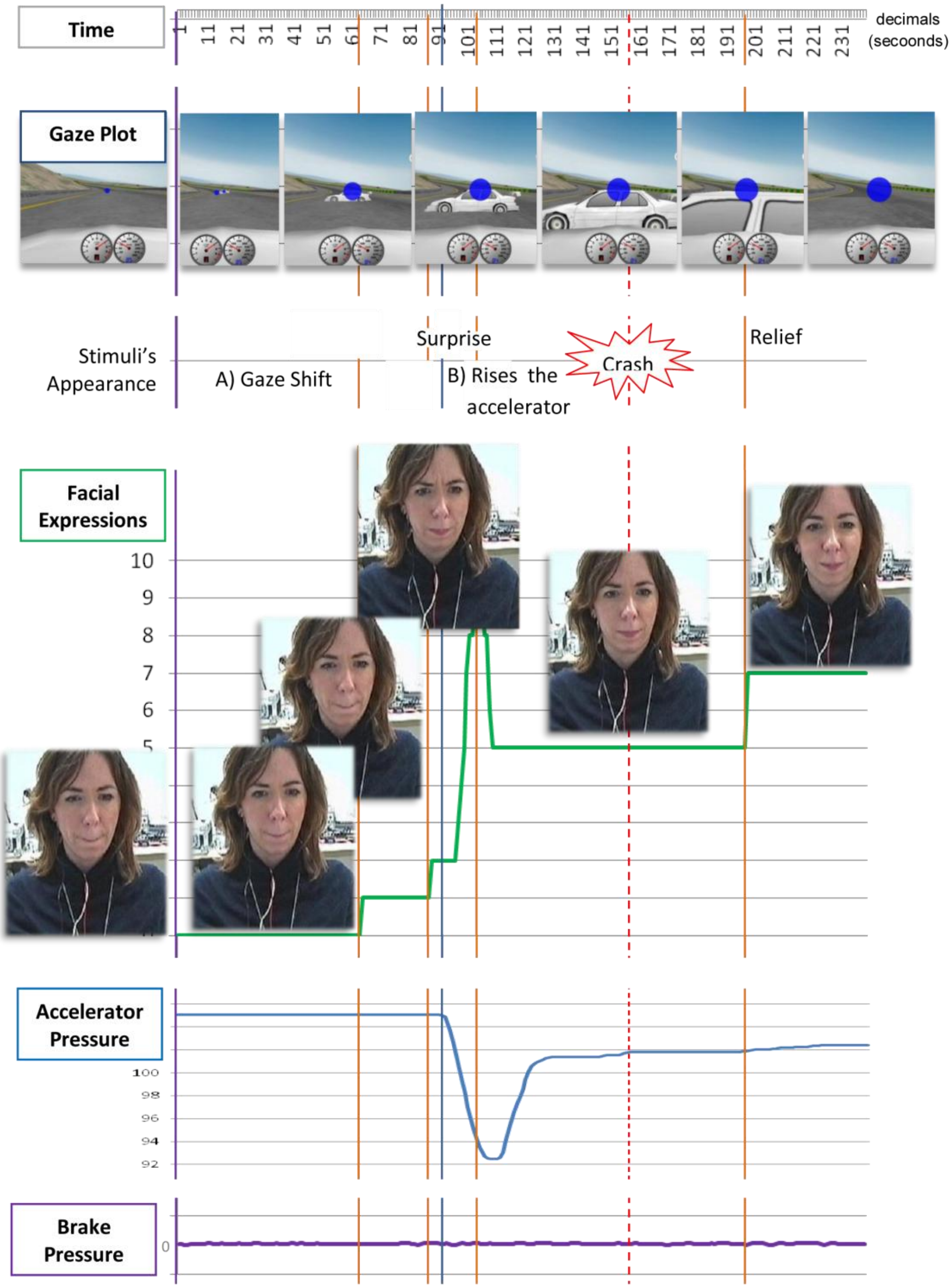
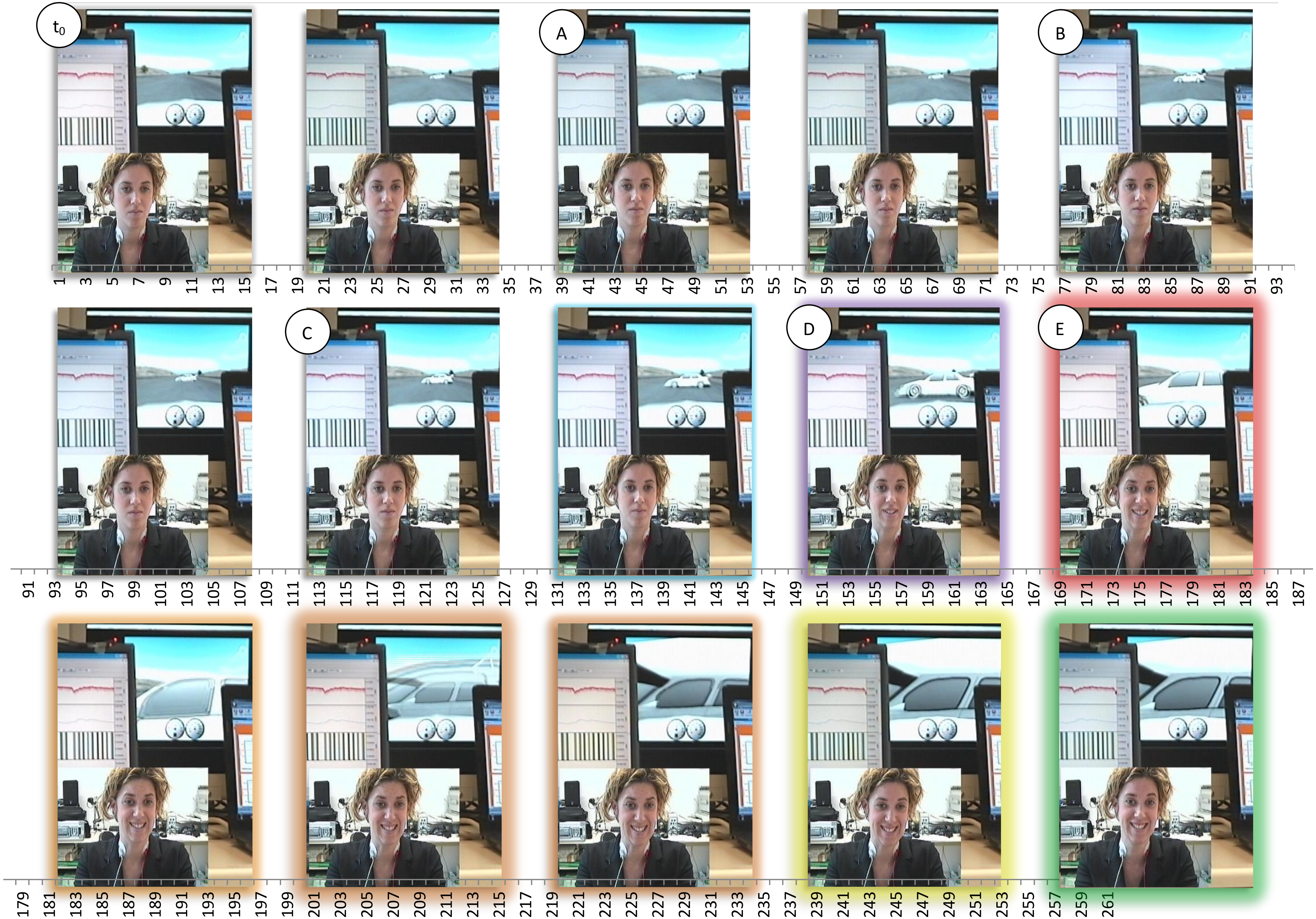


Figure 54. Reaction to the surprise event in the virtual condition. As for the fisrt study, The driver performed no action on the brake while facing the surprise event. From facial expression analysis it is possible to evaluate that the driver actually has seen the object. Some early surprise configurations (e.g. A.U. 1, 2, 5, 15) appears, while no pressure on the brake is registered. Right after the crash is not possible to see concern, but rather positive facial configurations e.g. A.U. 6, 12,13. Being aware that the virtual context bring no real harm consequences, may be the crucial difference that slows RTs in the virtual setting. This pattern can be observed in almost all cases of run over the obstacle (Figure 55 at the following page)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4.4. Discussions

Reaction times and Validity

RTs were slower in virtual condition then real driving condition. It is safe to assume that even if the car setting and the task were the same, in the virtual setting operate other variables that systematically slow the reaction times of the drivers of almost .50 seconds. That result suggest that it would be not safe to neither generalize nor export reaction times taken from this kind of virtual setting in the process of reconstructing driving accidents. Real driving data should be preferred when interest in knowing how long does it take to see, recognize, react and regulate the response to danger, as no absolute validity was found on times.

Different consideration must be done when talking about relative validity. There was a direct correspondence between effects of different variations in real-life and virtual driving situation (Godley, Triggs & Fildes, 2002).

In fact the virtual driving condition seems to keep some crucial features of the real driving data that are safe to assume could be generalized in real driving conditions. In fact no differences for type of stimuli were found between the two driving conditions. All the drivers in the real driving and all the drivers in the virtual TORCS driving were influenced in the same way by the type of stimuli and the psychological frames of mind that we manipulated. A two second warning was sufficient to reduce perception an decision making time in recognize that there was a danger, and start the motor response before the conditions without warning, in both conditions. The deceptive and surprise event slowed the ability of the driver to recognize that the danger was actually present in their visual field, in the same way as the first stimuli did. Also the lack of mental information on the way the danger had to be faced was systematically slowed by the mental information we manipulated with the surprise stimuli, in the real driving condition as well as in the virtual TORCS driving condition.

The test implemented in the virtual driving can be used to compare results on the manipulation of expectations and learning effects as results validated compared to real-life data, as it was validated for speed and physiological parameters (Li, J., Zhao, X., Xu, S., Ma, J., & Rong, J. 2013).

Performance and the influence of these mental states were not affected by virtual setting. Attention and perceptional process could be studied improved and trained even in a virtual setting, as were influenced by expectations in the same way in real and virtual driving condition.
Moreover the fact that the difference between the first no-warning red, and the second one that appeared later in the randomize sequence, were significant meaning that the drivers acquired a set of skills and correct expectations that improved their performance, making the responses faster, even after few trials.
That is to say that this kind of task is could actually be used in virtual setting in order to potentially train driver's reaction times to different type of meanings and danger.
The overall reaction times could be still slower, but it will be still possible work on the different conditions in order to improve the preparation of the drivers.
If a training can be created in order to help driver foster correct set of answers in less time, that could be done in virtual setting, knowing that the improvement in improving automatism towards surprise or deceptive events, follows similar patterns even in real driving. This kind of virtual learning should be tested back in real driving tests, but our results begin to furnish some measurement in order to set up potential trainings that works in that direction for prevention.

But why the reaction times were slower in the virtual setting? And what particular aspects of the reaction process are slowed by the virtual setting?

The answers could be found in the micro analysis of the single actions of the drivers during the process.

The fact that only Phase A, B and D were influenced by the virtual driving condition, suggest that the slowing effect of the virtual setting does not affect all the driving operations, but specifically the ones related to specific moment of perceiving some changes in the environment, making sense of the stimuli, and evaluation of the situation. While no influence on the reaction times on the action on the pedals, when the driving decision are already made (Phase C and E).

In the virtual setting the stimuli seems to be less salient as orientation of attention towards the light/surprise event were slower. At the same time drivers seems to be slower in realizing that the change in the virtual scenario have a relevant implication for their driving safety and the reaction on the accelerator is not as prompt as in real driving.

Physiological Activation and Concentration

Eye tracking and HRV analysis has shown that workload during driving, as well as while performing the task is sensitive to changes in driver workload and depends on the stimuli (Harms & Pattern, 2003; Jahn, Oehme, Krems, & Gelau, 2005).

Driving in a simulator has an impact on physiological activation, that is comparable to the physiological activation reported in literature for real-life driving. The levels of the arousal are high at the beginning of the driving, but then they decrease to more low levels of activation by the end of the test, Indicating that drivers learn to reduce the level of resources activated for the normal and task driving. Drivers learn to optimize attentional resource very quickly, (about 80 seconds are enough) and that can be noticed also for the use of peripheral view that is being used steadily by 35-38% of the sample already before the third stimuli, indicating that the drivers have enough attentional resources to spread the visual field to include wider visual angles of perception spread, thus detecting faster the stimuli.

Driving with the task is not a font of activation per se, but it has an impact only when is the first time the drivers start using the simulator and driving in the virtual environment and the cognitive load.

I. When repeating the task without cognitive load, the levels of activation are almost comparable to the activation requested to watch a neutral video.
II. When repeating the task with a cognitive load such as keep a constant and fixed speed while driving and responding to the task. The physiological level of activation remains always high and constant during all the time of the test, in normal driving condition and while driving and responding to the test too. The levels of activation are higher than the initial drive in the virtual condition as well as than the levels of the repetition without the cognitive load.

Therefore driving and responding to hazard stimuli in the virtual environment are activities that require an activation that decrease thru time, that can be trained rapidly for a better control of the resource employed, unless a cognitive load is introduced.

In fact, as far as the physiological parameters that are related to the Pre Frontal Cortex (PFC) that is involved in regulating the executive functions, results of SDNN shows that the level of concentration remain constant, and can be minimal for repetition without a cognitive load, and it is constantly high with the cognitive load, but is less influence by time, rather by the type of task.

Note that for this particular phase of the test we did not randomize the driving conditions and we did not have the time to analyze the overall RTs of the repetition condition, as they would have been biased by the learning effect and not informative on absolute and relative RTs as we were mainly interested in updating and comparing RTs in different setting. Priority was given to measure the same test in two different contexts under the same experimental conditions. However we hypothesize that the RTs in the repetition task would be significantly faster than in the first time they faced the test, as the data about HR and eye tracking are showing us an optimization of cognitive resource that could lead to a faster RTs.

Our hypothesis is that danger and risk perception related to virtual stimuli are less relevant and the reaction to danger is mediated by virtual context in which the driver knows he is not driving a real car. Thus the habitual reaction and mechanism may be not activated by procedural thinking; the responses have to be adapted, and thus the slowed reaction times. This is one possible explanation, and more research must be done in order to better explain the phenomenon. While moving on these two different levels of virtual vs. habitual real driving, the driver could reduce the cognitive and emotional resource to prompt a faster response. This includes the time spent looking in the peripheries of visual field as well as scanning and monitoring of the warning system (Harbluk, Noy, Trbovich, & Eizenman, 2007; Recarte & Nunes, 2000). However our explanation can be supported also by the slowing time in the reaction time of the passage to the brake (Phase D).

In fact the decision to move the foot in order to brake is not a reflex, but require a complex motor coordination, and it is slowed down in the virtual condition only for those type of stimuli were the driver was completely off guard (1°R and surprise event), the response to perform was not as automated as in real driving, requesting more time to be translated in action, and the risk perception or arousal activation was not activated to help faster the response on the brake.

To sustain this hypothesis in Study #3 will be shown the importance of emotions and risk perception in braking responses, in both real and virtual driving, with some interesting cases of no reaction to the surprise event, suggesting once more how attention and decision making process systematically impact on the reaction times more than the simple motor execution on the pedals.

In particular we will investigate which elements of a more realistic virtual simulation could be used to train expectations in driving condition that cannot be recreated easily and yet safely in real-life driving such as the pedestrian crossing.

Chapter 5
Study 3

Translation of Expectations in Realistic Stimuli

Validation of Pedestrian Sighting in Urban Virtual Environment

5.1. Objectives

The results of the first two studies seems to encourage the use of driving simulator for measuring and training specific aspects of the reaction process to danger, rather than absolute reactions to real driving dangers. In particular virtual simulation proved to be relative validated for testing the influence of expectations on visual attention and decision making process on pedals, with an absolute slowing in virtual reaction times of mean .50 seconds, but at the same time with the same effect of the manipulation expectations on reaction times.

These results were achieved using a specific sequence of colored light and a surprise event in both real and in a virtual simulator driving confirming the influence of the type of stimuli on the reaction times (Green, 2000; Summala 2000). So the further question would be whether the results obtained with our nonfigurative stimuli, could be translated into realistic dangers in a more complex real city environment, translating the manipulation of different levels of expectation into realistic dangers .

Could the relative effects that manipulate drivers RT work also for other stimuli?

Another question that arose from the previous studies is whether using a driving simulator that increase the sense of immersion and flow experience with a wider screen and a dynamic kinesics systems, could actually reduce the impact of the virtual setting in slowing the reaction times, compared to real driving.

Is the virtual reality "real" enough to reach absolute validity?

Those new questions would request a wider set of tests (Figure 56) in order to measure both the main and interactions effects of reality-based dangers x increased realism of the driving simulator on reaction times. For instance we should test the same driving scenarios that would have not added other variables to the task (i.e. nature of the track, average speed), we should test the same track on a more complex and immersive simulator and test the same stimuli on the new simulator as well as the new stimuli on the old simulator and on real road.

We would have be sure that the setting on the car would have matched the one we used on the first two studios (i.e. distance of the pedals, pedal resistance, exclusion of the clutch) and we would have be sure that the dangers translation would create the same levels of anger predictability that could be matched with the ones used to measure the different reactions times.

For these specific reasons, we split the issue one main effect at time. The present study will be the initial pilot step to measure the effect of translating the different levels of expectations created by nonfigurative dangers, in reality-based dangers on visual attention.

Starting from the validation of the new stimuli, then the other steps could start to be studied. It will be studied just the Gaze Response Time (GRT), as it would not be affected by the equipment used.

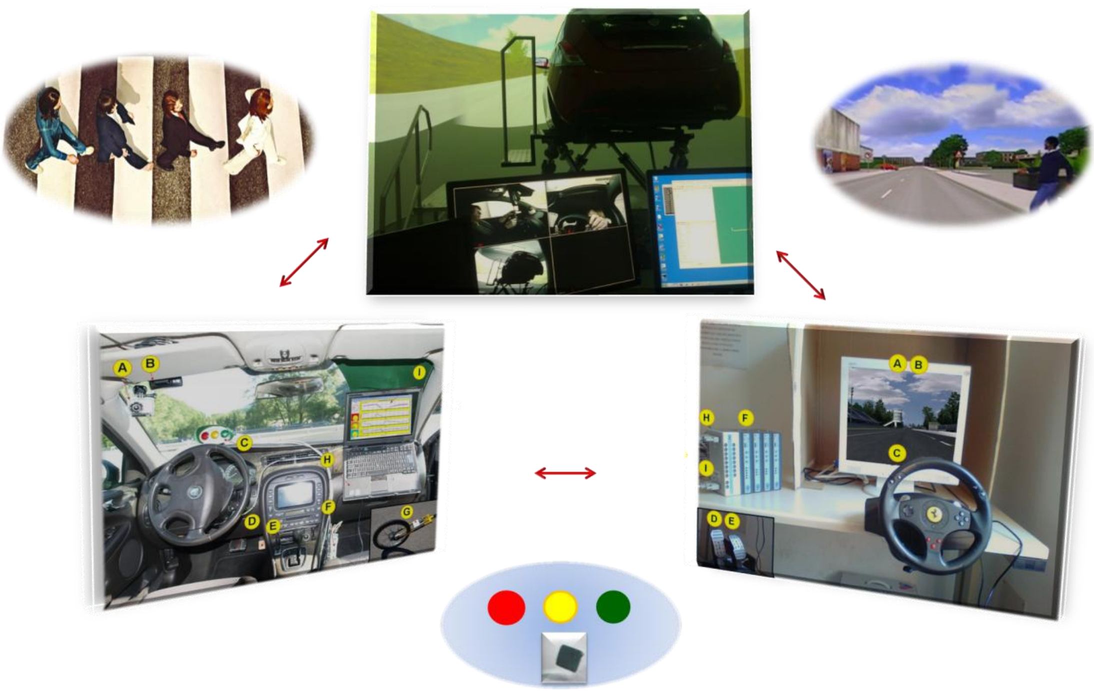


Figure 56. Different Stimuli and different driving conditions. It is possible to transfer the knowledge and learning to one stimuli, made inside one simulator, to another one? Can this process be transferred for more complex and realistic environment? And it is possible to relate these data with real life conditions?

Pedestrian Crossing and Road Signs

GRT will be used to investigate visual attention and visual search towards a new and more realistic target: Pedestrian crossing the road.

We decided to focus our efforts on this particular driving situation as is a relevant issue on urban environment, it involves drivers and citizen even without the driving license and would have let us manipulate different condition in which test road interaction, as is potentially one of the situation with a high variety of possibility and combination. In fact, even if the road law precisely states that pedestrian must cross only in near road sign, it is possible for the driver to face pedestrian crossing in everyday driving even far from road signs or in particular spots of the road (e.g. along any point of a cross walks) that are less regulated then a road interactions with other cars, that could happen only inside specific point of the roadway that are road injunctions.

Pedestrian crossing could also be regulated by specific road signs and traffic lights, or could happen in totally unexpected situations (e.g. behind a corner, after a tree, behind a parked car)

These different situations are particularly interesting for our research as would let us manipulate different levels of expectations of the crossing, and relate these expectations with RTs. In particular saccades movement will be the first and part of the RTs process and it will be tested as function of expectations created by visibility of the pedestrian and the possible warnings created by road signs and road configurations of an urban scenario.

Visual attention towards pedestrian crossing road sign will be studied in relation to manipulation of presence/absence of road signs as warning, and a manipulation of type of pedestrian crossing as expectation.

As a comparison among the sample is particularly critical the Barratt Impulsiveness Scale (BIS-11; Patton et al., 1995) will be used along the other measures, to assess the personality/behavioral construct of impulsiveness of drivers in order to evaluate the sample and spot eventual outliers.

BIS11 is a multi-faceted construct and is found to relate with reactions times and impulsivity (Stanford, Mathias, Dougherty, Lake, Anderson, Patton, 2009). Is composed by six first-order factors: attention, motor, self-control, cognitive complexity, perseverance, and cognitive instability impulsiveness; and three second-order factors: attentional, motor, and non-planning impulsiveness.

5.2. Method

The driving simulator

For the experimentation here presented, the driving simulator recently acquired (2012) by University of Florence was used (Figure 57).

It is a full scale dynamic simulator provided by AutoSim (Norway), consisting of a full vehicle cabin (Lancia Ypsilon) installed on a 6 axes Stewart platform. The scenario is projected by 4 projectors on a 200 degrees cylindrical screen, while rear vision is obtained by means of three LCD monitors, replacing rear mirrors. A multichannel sound system produces sounds and noise. A city terrain was chosen among those available, in which autonomous traffic and pedestrians were added; in particular were added pedestrians meant to represent the hazard situations under study.

Figure 57. Driving simulato used for this third studio. It was an AutoSim (Norway), consisting of a full vehicle cabin (Lancia Ypsilon) installed on a 6 axes Stewart platform, and programmed by Prof. Virga and Vangi of the Florence University, IT

Translating the dangers

Five different setting of pedestrian crossing were implemented reproducing the 4 situations drivers of study #1 and #2 had to face.

An urban scenario of a city center with medium traffic environment was created, with clear visibility and sun shining, as it was in the previous two studies (Figure 58). The manipulation of expectations was carried out by manipulating the different crossing condition of pedestrian along with road signs congruency.

More specifically, the warnings would be represented by vertical and horizontal pedestrian crossing's road signs, with pedestrian crossing near road sign (conditions 1) and pedestrian crossing far from pedestrian crossing (conditions 2). While the levels of drivers expectations would be represented by predictable pedestrian crossing, with pedestrian that manifest their intention to start the cross, standing on the sidewalk and walking towards the street (conditions A) vs. pedestrian crossing the road suddenly, without manifesting any previous intention to cross the street (conditions B) (table 12).

A randomized sequence was created like in the previous two studies, alternating five different conditions for the drivers:

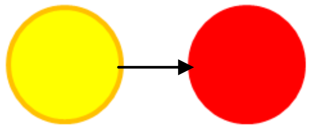
Figure 58. Example of the urban environment and driving condition for traffic and weather used to build the experimental task.

1st Stimuli

No warning, time uncertainty, novelty (Condition A2)

A pedestrian is placed on the right of the roadway, on a walk side. When the driver is 30 meters from the pedestrian, it starts its movement crossing suddenly the road in a zone of the street where no zebra crossing or pedestrian crossing signals are present.

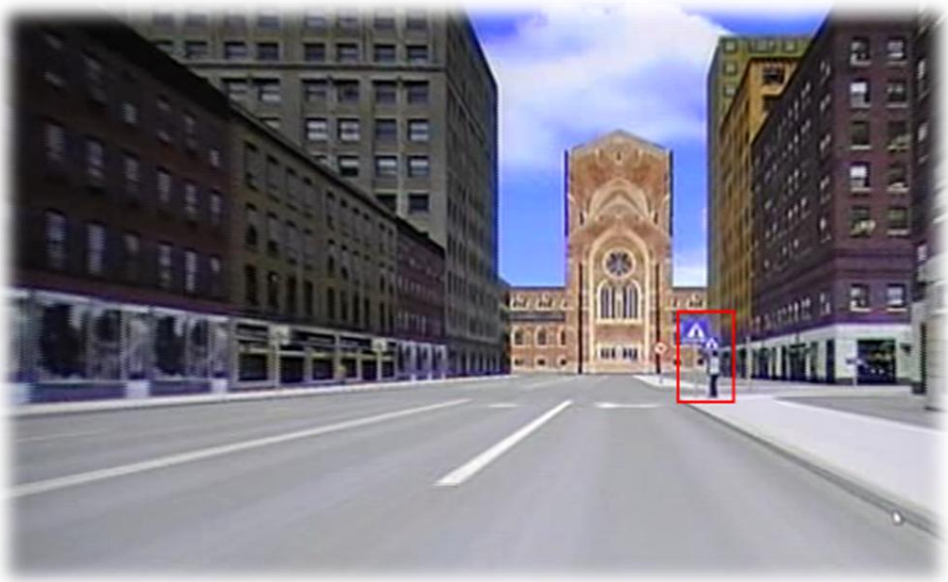
Two-seconds Warning



Two-seconds warning, time certainty, known stimuli (Condition A1)

Two seconds before approaching the target pedestrian, a series of pedestrian crossing warnings is visible on the road as vertical and horizontal road signs. A pedestrian is visible near zebra crossing. When the driver is 30 meters away from the pedestrian, it will start its crossing on the horizontal signs and near a vertical signs of pedestrian crossing.

In this condition the driver is alerted and can foresee what will happen.



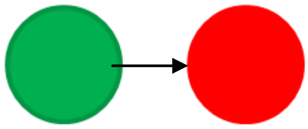
2nd time inside the randomized sequence

Time uncertainty, known stimuli (Condition B1)

A pedestrian is hidden behind a car, near a crossing sign and zebra crossing.

It is not visible on the road, so no warning is given, but its presence it is potentially predictable by the presence of the road signs. The drivers may expect a crossing and this mental condition matches the second red inside the randomized sequence in the previous studies, as the driver already know what he will face, but it does not know if or when the danger will appear until the moment it manifest itself. When the driver is 30 meters from the pedestrian, then the pedestrian will start its crossing on the horizontal signs and near a vertical signs of pedestrian crossing.

Misleading Condition



Two-seconds warning, time certainty, known stimuli (Condition B3)

Disguised warning before crossing. A pedestrian is placed still on the left side of the road and will remain immobile till the driver overcome his position.

At this point a new pedestrian on the right will consequently cross the street.

No warning is given by the presence of road sign nor can be inferred by the presence of the pedestrian that it is covered by the car. The presence of still pedestrian on the left may have captured the attention of the driver (i.e. the appearance of a Green light). but as the pedestrian remain still it becomes of no concern for the driver that has passed away the pedestrian feeling that the danger is not present. By this point of the sequence no pedestrian crossed right after another, and this previous rule may influence the driver's beliefs about having passed the danger. In this particular state of mind the driver has, instead, to face a new pedestrian crossing.

Surprise Event

No warning, time uncertainty, surprise event (Condition B2)

While proceeding along the roadway a pedestrian will start crossing the road exit from a hidden position, behind a tree, far from any pedestrian crossing sigs and impossible to be noticed until the very beginning of his cross moving, when it has already reached the right side of the roadway.

It will match the surprise event condition as the driver cannot expect a pedestrian crossing at this particular moment, and from this particular side of the roadway, making the crossing totally unexpected and unpredictable.

The pedestrian start its movement when the driver is 30 meters away so he will have the same time space to brake as in the other conditions.

Table 12. Predictability x Road Signs Manipulation of the expectations of the drivers for pedestrian crossing

PREDICTABLE CROSSING	
With Road Signs (A 1)	Without Road Signs (A 2)

A 1

A 2

UNPREDICTABLE CROSSING		
With Road Signs (B 1)	Without Road Sign (B 2)	Without Road Sign, 2nd Time (B 3)

B 1

B 2

B 3

Procedure

Subjects were invited to sit in the simulator regulate the driving seat and fasten the seat belt. Participants were asked to drive normally in the virtual scenario, just respecting traffic code, speed limits and road rules. All the scenarios were characterized by middle road traffic and each hazard appears after two minutes of simulated driving. The sequence of the road interactions was randomized for each participant, in order to avoid sequence effects. In each scenario the different type of pedestrian crossing were placed in different places of the virtual city, in specific spots of the town where they were bound to pass. The driving session lasted about 13-22 minutes, depending on the average speed of the participant.

During the driving session, their eye movements were recorded by eye tracker (Tobii x 120), supported by a pc Acer Aspire 5930G (Intel Core Duo 2.26GHz, 4 GB DDR2 e NVIDIA Ge-Force 9600M GT 512 MB RAM) and synchronized with the driving simulator by a video camera.

After some minutes to define the subject's behavior baseline, the scenarios were randomly administered to the subjects. At the end of the session debriefing information were given.

If participants felt at any moment simulator sickness the recoding process would terminate and drivers asked if they wanted to proceed or terminate freely the experimental session.

Calculation

Gaze Response Time (GRT) will be calculated. In corresponding to each hazard the frequency of the drivers' fixations (fixation count FC) (Underwood, Chapman, Brocklehurst, Underwood, & Crundall, 2003) and the duration of each fixation (fixation length FL) were calculated using Tobii Studio 2.0 eye-tracking software.

Analyses were conducted on the seconds preceding the participants' approach to each pedestrian interaction, a window of time considered enough to study the visual and motor reaction to different type of potential dangers (Green M., 2000; Summala, 2000). Visual attention was calculated measuring whether the subject was paying attention to the pedestrian near the crosswalk, before the crossing (Pedestrian Sighting) and the Time to First Fixation (TTFF), that is the time it took for the driver to shift his/her gaze towards pedestrian, once the crossing movement has stared (Figure 59).

Data for all the other phases of the RT process were recorded, but it was not possible to analyze the data for this specific session of the research.

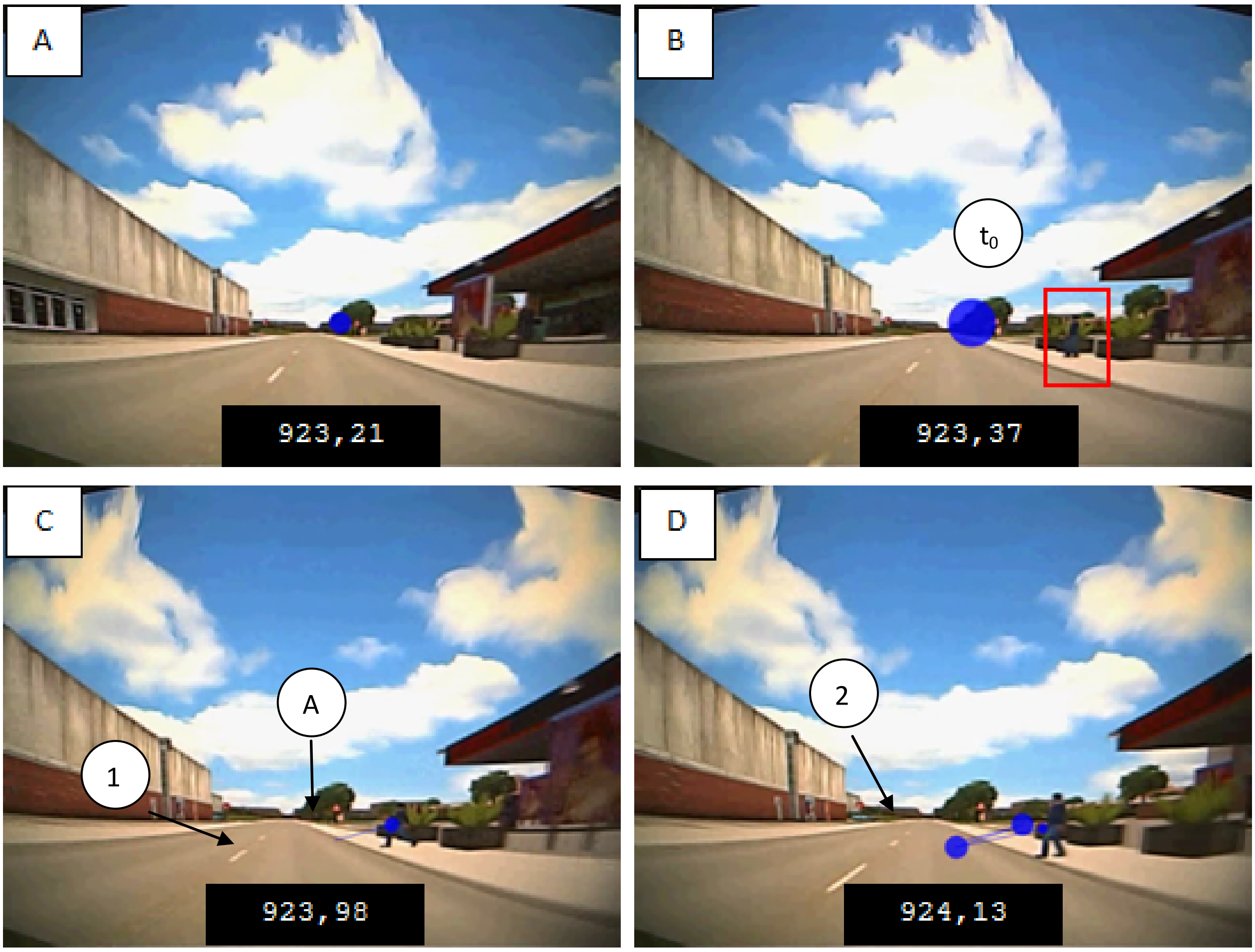


Figure 59. Calculation of the time needed from the beginning of the movement of the pedestrian, to the shift of driver's gaze direction toward the pedestrian (Time to First Fixation)

Sample

As no differences for gender or age emerged from the previous two studies, a uniform sample, without differences for age or gender was selected to control the simulator sickness (SS) variable. In fact as no differences emerged in GRT for age, gender and BMI but as SS was found to affect Gaze movement, and was be related in literature to gender and age (Brooks, Goodenough, Crisler, Klein, Alley, Koon, Wills, 2010) we decided to choose mostly young male drivers with more than 5 years of driving experience. Thirty drivers (25 males, 5 females) participated voluntarily in this study. They were regular drivers (about 12000 km/year), with a driving license for more than three years (*M* = 8.31, *SD* = 3.72), and were aged between 21-31 years (*M* = 26.39, *SD* = 3.84).

To compare the results with the previous studies a sub-sample of 39 drivers coming from the three studies was created. The population that was used as reference for the comparison was selected among the previous sample to only male younger than 35 years old. As can be seen in Figure 60 the male sample for real-life driving condition was the more crucial for the comparison as is less numerous, so it was set as reference for group sampling in the different conditions in order to reach at least 10 drivers in each group for the comparison. The sub-sample resulted aged between 21-35 years old *M* = 28.75, *SD* = 4.5 (Figure 61)

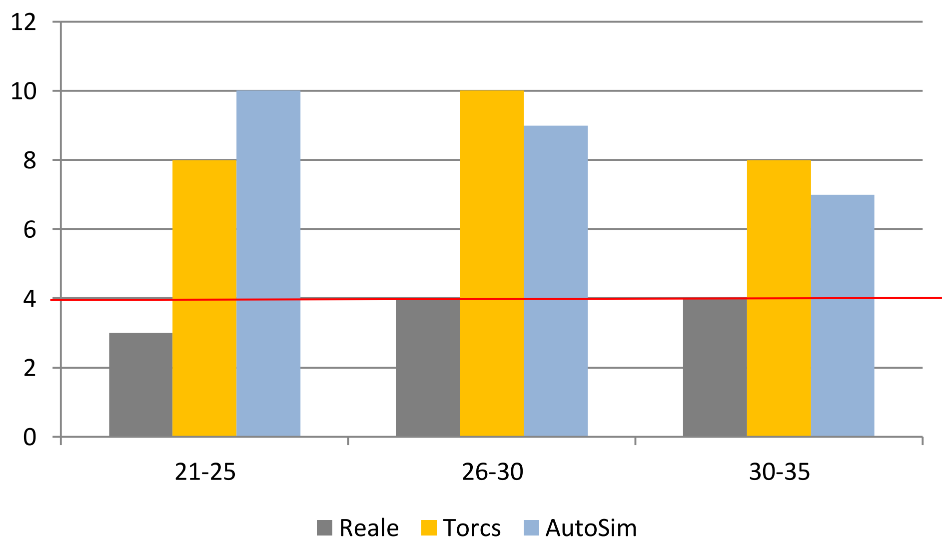


Figure 60. Young man drivers in the three different samples of the three different studies. Distribution of the sample of the first study was used as cut off for the other two samples, in order to build the sub-sample for comparing the three studies.

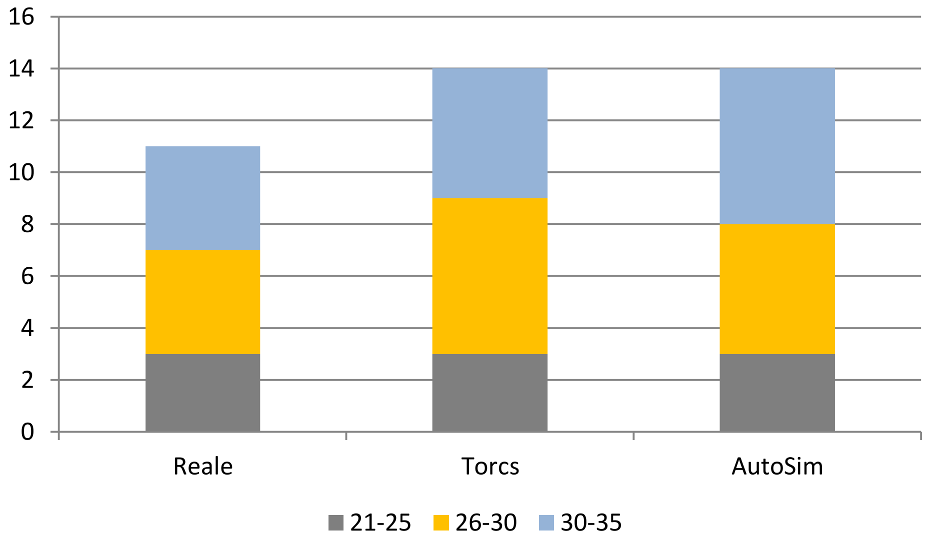


Figure 61. Sample of young man drivers in the three different samples. The comparison was done for three groups of 11, 14 and 14 drivers with similar distribution for age and gender. Note that age was not used as an independent factor to segment the group, but rather it was used to build a sample for the statistical analysis.

The sub-sample's score for the Italian scale of Barratt Impulsiveness Scale BISS 11 for first order factors were: Attention *M* = 9.5, *SD* = 1.9; Cognitive Instability *M* = 11.0, *SD* = 2.3; Motor *M* = 12.6, *SD* = 2.3; Self-Control *M* = 12.6, *SD* = 2.3; Cognitive Complexity *M* = 10.2, *SD* = 2.3; Perseverance *M* = 7.3, *SD* = 1.5; Cognitive Instability *M* = 6.6, *SD* = 1.3.

While second order factors were: Attention *M* = 16.1, *SD* = 2.4; Motor *M* = 18.3, *SD* = 2.5; Non planning M = 22.9, *SD* = 3.4.

The scores for the sub sample formed for comparing the samples were not statistically different from the scores to the second factors of the TORCS driving condition: Attention F(1,28) = .031, *p* = .861, η^2 = .001; Motor F(1,28) = 2.146, *p* = .155, η^2 = .076; nor for Non planning F(1,28) = .141, *p* = .771, η^2 = .005 impulsivity, so two sub-sample were considered comparable.

5.3. Results

1. Pedestrian sighting

As shown in Table 13, the frequency of drivers' attention towards the crossing area was different for the different scenarios. In the A1 condition, with a pedestrian near a road sign warning, 78% of drivers were looking at the pedestrian standing near the crosswalk, even before the pedestrian actually started crossing. In the surprise condition B2, the fixations at the crossing area were significantly less frequent, with only 21% of drivers looking towards the crosswalk before the pedestrian started its crossing. In the A2 condition, pedestrian standing without road signs, and B1 condition, hidden pedestrian near road sign, the probability of the driver to look at the crossing area before pedestrian's crossing was comparable to the probability of the driver to not look there. On the other hand, in the B3 condition was more frequent the situation where the driver did not looked at the pedestrian before the crossing (27%) rather than the driver looking at the pedestrian before (73%).

The difference was not statistically significant, yet the Odds Ratio for the driver to not look at the pedestrian before, are still higher than the probability of the driver to look at the pedestrian before.

Table 13: Driver already looking at the pedestrian near the crosswalk

Pedestrian sighting	Fixations				
	Yes	No	χ^2		Odds Ratio
A1: Road sign warning, predictable crossing	78%	22%	7.35	**	12.96
A2: Without road sign warning, predictable crossing	65%	35%	2.13		3.52
B1: Road sign warning, unpredictable crossing	50%	50%	0.00		1.00
B2: Without road sign warning, unpredictable	21%	79%	6.36	*	0.07
B3: Without road sign, misleading, unpredictable	27%	73%	2.27		0.14

2. Delay of pedestrian Sighting

In case the driver was not looking at the pedestrian approaching the crosswalk, the time it took for the driver to shift his/her gaze towards the moving pedestrian once the crossing has started, was dependent on the experimental conditions. The means of time needed to shift the attention were significantly different (Table 14).

The delays in the sighting were shorter in the A1 condition, with a mean of detection of the pedestrian's movement of 0.06 seconds. Sighting is slightly slower in the A2 condition (predictable crossing without road signs). In the condition where the crossing was not predictable, the time needed was significantly longer, going from 0.20 seconds in B1 condition, to a maximum of 0.53 seconds in B2 condition, that is almost half a second longer then the optimal A1 condition.

The difference in the time to the first fixation to-wards the pedestrian was analyzed using SPSS through General Linear Model 2x2 (Road Signs x Predictability). The ANOVA analysis reported a main effect for the Predictability $F(1,30) = 17.835$; $p = .001$, but not for the Road Signs $F(1,30) = 3.463$; $p = .087$, nor for the interaction effect $F(1,30) = 16.04$; $p = .229$, as can be seen in Figure 62.

Table 14: Gaze Response Time Towards the Moving Pedestrian

Time to First Fixation of the Moving Pedestrian	Delay (sec.)			
	M	*SD*	*t*	*p*
A1: With road signs - Predictable	0.06	0.14	1.99	0.06
A2: Without road signs - Predictable	0.10	0.17	2.73	0.01
B1: With road signs - Unpredictable	0.21	0.30	3.34	0.00
B2: Without road signs - Unpredictable	0.53	0.42	5.61	0.00
B3: Without road signs - Unpredictable - Misleading	0.47	0.33	4.72	0.00

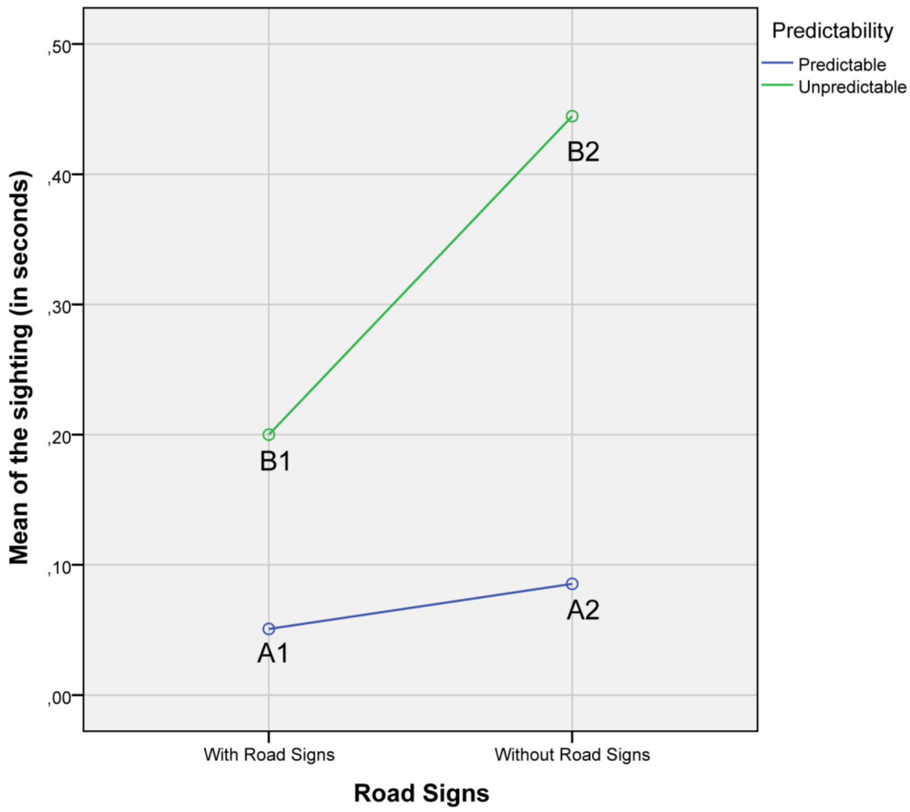


Figure 62. Time for driver to shift gaze towards the moving pedestrian in the different conditions.

3. Comparison of GRT with Study #1 & #2

Considering the sub-sample for the comparison of three studies for GRT, it is possible to notice first of all that even for this sub-sample, the results of the previous two studies are confirmed. Even sampling only male drivers for study #1 and #2, it is possible to notice the same effect of type of stimuli and expectations on GRT, as can be seen in Figure 63. This confirms once again that there was no effect for gender or age in the previous two studies.

Considering the differences among the three driving condition, results shows that the main effect for the experimental conditions was also significant F(2,39) = 5.813, p = .008, η^2 = .301, underlying once more that there is no absolute validity of the driving simulators in GRT.

Post-hoc Tukey HSD test showed that the differences in the variance were significant different for Real-life driving vs. TORCS driving (p = .007), as emerged in study #2. However no differences were found between Real-life driving vs. AutoSim driving (p = .834), nor among TORCS driving vs. AutoSim driving (p = .103). These results appear to be contradictory, but looking at the interaction effect with the type of stimuli and expectations it is possible to find the explanation.

In fact the main effect for type of expectation created by the different stimuli was significant $F(4,39) = 8.556$, $p < .000$, $\eta^2 = .160$, and the interaction effect Type of stimuli x Experimental condition was in fact significant too $F(8,39) = 3.181$, $p = .004$, $\eta^2 = .124$.

As can be seen (Figure 63) AutoSim driving produced results that are similar to Real-life driving for the expectable and with warning conditions, while it produced GRT in the unexpected and surprise condition similar to the TORCS driving. Test of within-subjects contrasts reported that these differences were significant (Table 15).

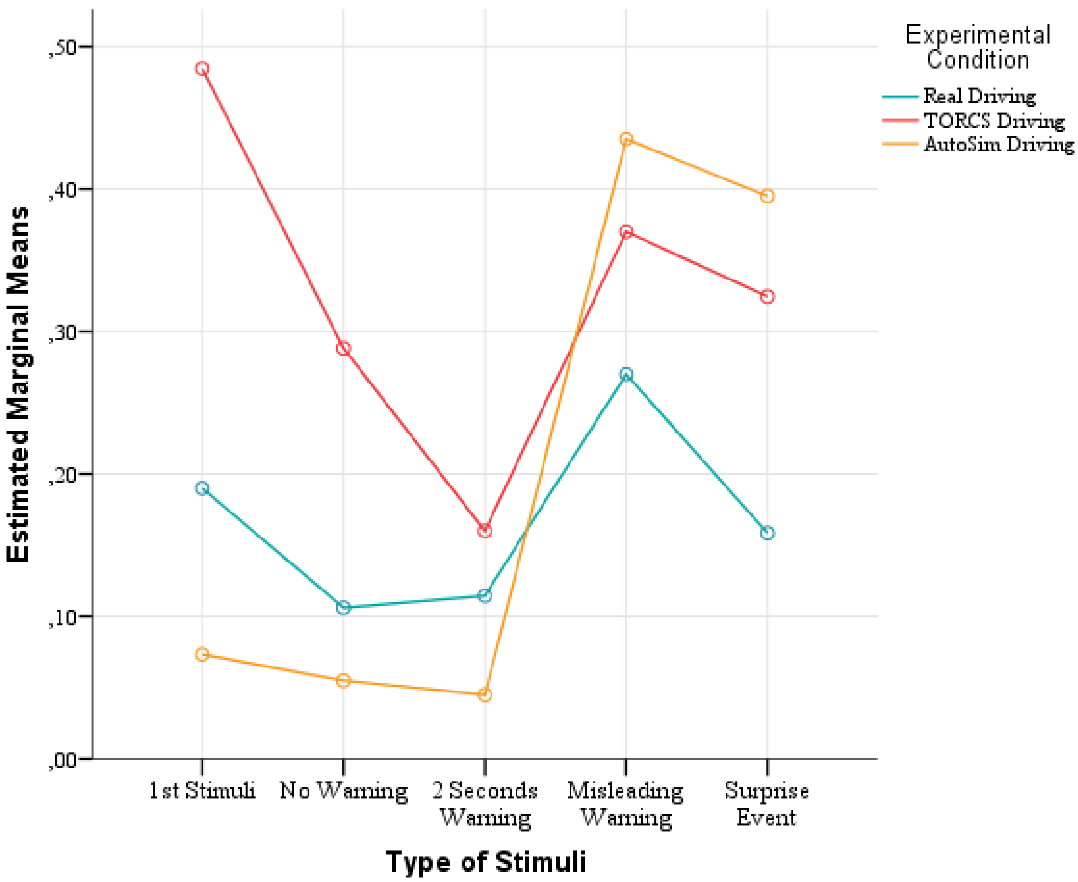


Figure 63. Interaction effect for Type of stimuli and driving condition for GRT

Table 15. Gaze Response Time x Driving Conditions (seconds)

	Real-Life		TORCS		AutoSim		Tests of Within-Subjects Contrasts *		
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	F	*p*	*η2*
1st Stimuli	0.26	0.20	0.47	0.17	0.07	0.18	-	-	-
No Warning	0.13	0.09	0.25	0.23	0.06	0.09	1.267	.298	.086
Two-Seconds Warning	0.08	0.09	0.20	0.19	0.05	0.11	4.557	.020	.252
Misleading condition	0.24	0.18	0.29	0.29	0.44	0.35	4.853	.016	.264
Surprise event	0.20	0.12	0.31	0.29	0.40	0.32	5.877	.008	.303

*

The Simple Contrast Comparison for Type of Stimuli X Driving Condition compares all the different stimuli to the GRT of the first stimuli.

5.4. Discussion

Pedestrian sighting and road sign expectations

Results confirm the hypothesis that pedestrian sighting depends on the experimental variables.

The more complex the scene in terms of road signs and exportability, the less driver look at the pedestrians before crossing, and the longer it takes to be aware of the movement of the pedestrian.

Road signs guarantee an optimal condition to detect potential hazard, but is the predictability of the crossing by itself makes a difference in time needed to realize when an hazard is already present. Road signs help in focusing the attention towards the target while approaching road interactions, but they are not the key factor to prompt the visual orientation towards target. The saliency and predictability of the crossing are the core elements, and may trigger the visual attention faster, even when no road signs are present. GRT is faster in the predictable conditions, whether the predictably is created by road signs or by the communicative intention manifested by the pedestrian to cross the road.

As far as the driving conditions comparison, the manipulation created by the different crossing conditions for this study proved to be relative validated. The ratio that guided the buildings of the scenario created an identical effect on GRT, as the one validated in the previous studies.

The specificity of the driving simulation and pedestrian crossing scenes, produced however two different GRT pattern:

I. One for predictable crossing that it resulted the fastest response compared to the other two driving conditions. This response was faster maybe because the saliency of the pedestrian capture driver attention even before the pedestrian would become an actual target for a safe crossing interaction. Compared to the colored light that appeared and disappeared on a fixed position of the visual field, a pedestrian on the walk side capture the attention while driving, modify the expectation of a crossing and thus speeding up the consequent time to recognize that the target stimuli is indeed moving. This advance orientation of attention help the driver may filter the visual attention on the specific target despite a more challenging and demanding driving context

II. And the slowest pattern for unexpected event, compared to the unexpected events in the previous studies. The unexpected pedestrian crossing may be slower to recognize as since no warning is given, nor expectation of a possible crossing is suggested by the driving condition, the driver cannot focus in advance his/her attention towards the pedestrian. This missing advance orientation of attention, evidently do not help the driver to understand what salient part of the driving context is becoming important to avoid the accident, as the urban driving condition is more complex and demanding then in the previous two studies. The response of the driver is less sensitive then real-life driving in perceiving the movement of the pedestrian as relevant change in the visual field.

It results that are not road signs or type of driving simulations that influence in an absolute way drivers' visual exploration, but rather the possibility to use the information that our perceptive system has recorded, the attentive system has filtered and oriented according to the saliency created by a particular driving condition. The complexity of this process significantly reflects itself then in RTs, already just for the Gaze orientation time.

The study presented several limitations. First the scenario can still be improved, as there could be more traffic on the road, in order to test if the pedestrian sighting can depend also from traffic conditions, as previously reported in literature (Underwood, 2005). Moreover the sample for further study can be improved in order to allow other statistical analysis, and could be controlled for gender and other variables that can impact on reaction times.

Nevertheless the experimental setting build up and tested for this study seem to be promising for further research, in order to obtain concrete data and precious information for specific trainings on drivers and pedestrian‘s expectations, and build safer pedestrian crosswalks.

For instance these specific results on GRT could encourage forth the use of driving simulation for projecting road injection.

Visual Exploration in Simulators and Safer Real Road Modification

With virtual driving simulations it is possible nowadays rebuilt the road configuration of different traffic injunctions as they are in reality.

As can be seen in Figure 64, if a particular critical area is identified where many road accidents or traffic violations are reported, it can easily be reconstructed in a virtual environment.

Then using an eyetracker system as exposed in these thesis could show where drivers are paying attention at, and what aspect of the road injunction create particular expectations that guide the drivers’ gaze movement.

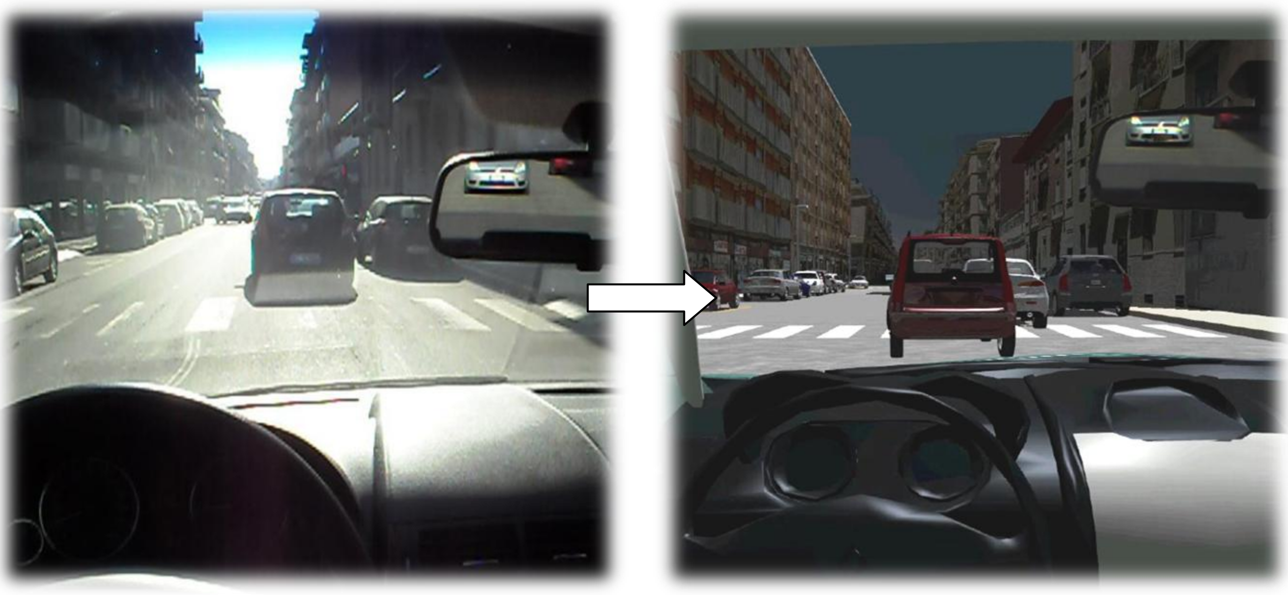


Figure 64. Real road interaction (left) re-build using ARAS 360° HD into a virtual simulation (right) that respect the exact dimension, speed and lightening of the real road interaction. This virtual simulation can be used to test Visual attention and RT to real danger in a safer environment.

At the same time the virtual environment can be modified in order to create a safer environment, and the modification can be tested with different samples, in order to establish what are the real modifications that can be done, without wasting money and efforts in useless or even dangerous modification for road safety.

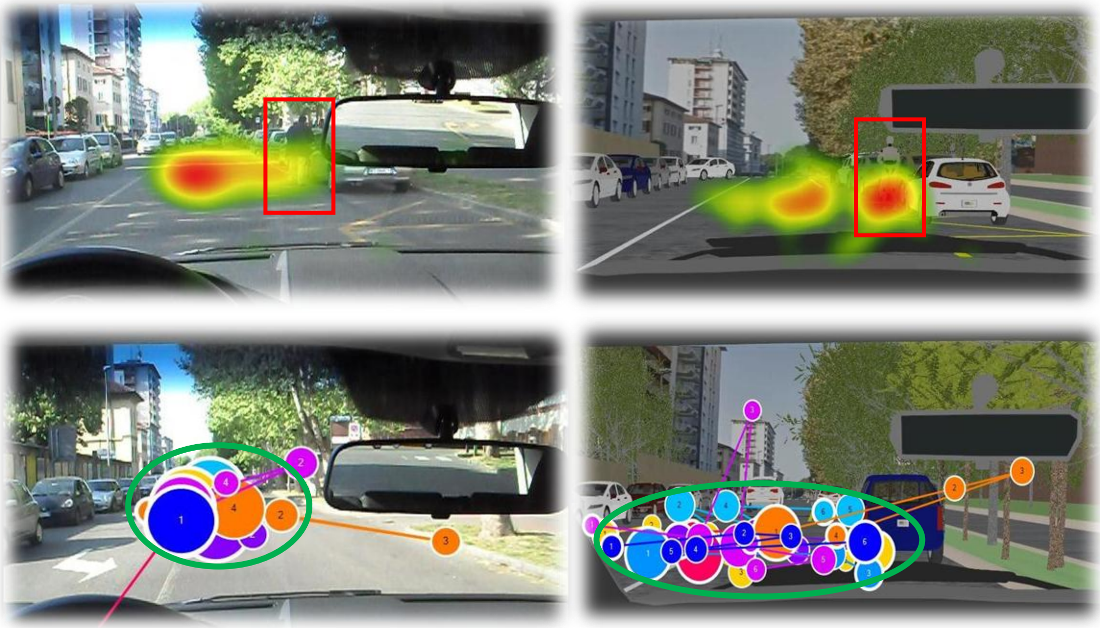


Figure 65. Using the same analysis validated in the study 3 it would be possible to record, measure and compare the shift in attention and decision making process in a virtual environment (images on the right), in order to asses under what condition a pedestrian can be detected faster and in a safer way. At the same way it would be possible to recognize what configuration of the real roadway (images on the left) may influence visual attention and create expectations in the drivers that may slow down the RTs.

For instance a pedestrian crossing could be simulated on the virtual condition and GRT measured. Then it would be possible to manipulate changes in the road environment that create different expectation in the drivers (such as: modify the height of the walk side, adding visibility to the intention to cross of the pedestrian, modify the structure of the roadway), in order to measure (Figure 65) in a statistically validated way what possible changes actually impact GRT for a safer pedestrian crossing.

Chapter 6
Conclusions

6.1. Attention, Decision Making, Emotions and Expectations

The present thesis had two main goals: on the one hand to update RTs as function of the human factor's variability bound to the attention and the decision making processes and to the emotional evaluation of potentially dangerous driving situations.

The second goal was to try to outline a methodological comparison between the various grades of virtual simulation: that is, to observe how driver's behavior would change in different experimental contexts, so to be able to evaluate whether virtual simulations, which could be validated by data collected in real-life driving, can be used to measure RTs.

The results supply measures and indications on the cognitive and executive aspects that influence driving in that critical phases that requires a driver's reaction to avoid a potential accident. These indication shows how important drivers' knowledge and expectations are to orient driving actions before a potential accident, and of how much time is needed to notice a danger according to the different levels of expectation elicited by the situation. The results show that it is possible to identify at least two different reaction times as a function of the subjective predictability of the danger to face: 1) a total reaction time of about 0.90 seconds for predictable situations, and 2) one of about 1.30 seconds for temporarily unforeseeable, and especially unexpected situations.

A difference of almost 0.40 seconds, which, at an urban speed of 50Km/h, represents a variance of almost 5.55 meters, equivalent of a two floors building. It is worth considering that these data represent central aggregators of a time variability which has been constantly proved and repeatedly bound to the typology of driving situation which the almost one hundred drivers, object of the three studies, have dealt with. More than the absolute numeric value, from the collected data it stands out clearly how the centrality of the response and of the times variance has essentially to be ascribed to the perception, attention regulation and decision making processes, more than the effective motor execution of the commands.

These psychological processes are directly trainable, as appears from the sequence effect, and training based on the concrete recognition of the different driving dangers and situations, can bring to more effective, coherent and rapid responses in emergency situations.

In this regard the second goal of the research has shown how the use of different driving simulators can be critically sustained for some specific objective, but not for others.

In particular, two considerations stand out as principal: the first consideration is that with respect to reaction times, neither of the two tested systems has succeeded in having absolute validity relating to the data collected in real-life driving.

The second consideration, instead, is related to learning: an effect of relative validity, which seems reproducing real phenomena, but with an impact on reaction times systematically mediated, has been detected. Immersion and verisimilitude are important factors, as well as movement accuracy, but they are not essential. What seems really crucial, for learning, is to create driving situations which manipulate, in an aware and proved way, the drivers' expectations. Even a single screen simulator can give results which are comparable to moving simulators with projectors inside a real car. At the same time, not necessarily the results are related to real situations.

When dangers are transposed from real to virtual situations, it is always important to consider the extent of the driver's psychological expectations and of the situation, referring to data found in the literature or directly to validated studies in the real world, if possible.

The research work has also pointed out conclusions for specific behavioral features of driving, which can better clarify the impact of the so-called "human factor", to driving:

Gaze Response Time

From a psychological point of view our attentive system is able to filter environmental stimuli depending on the purposes, interests and relevance that the stimulus has to the subject.

Results show that drivers activate signals of recognition or emotional evaluation (direction of gaze or emotional actions of facial muscles) before performing an action on the brake pedal. In the reaction time process it is possible to identify a specific spotting phase, with the average length of 18ms, preceding the action of diminishing pressure on the gas pedal, in which the subject starts to evaluate the stimulus itself (GRT).

Moreover results show that the manipulation of anticipations about what is going to happen next can interact with the attentive system, filtering or suppressing signals that the driver does not consider relevant in that precise moment. Coherently with psychological literature, in these tests we have shown also that, while driving, the help of an alert system alone is not sufficient to reduce accidents, when the driver’s expectation is not adequate. In particular, in the Misleading condition, both real and virtual, drivers seeing the green light perceive from the environment that there is no danger; hence, when the red light appear, they filter the physical stimulation of the stimulus in 24 ms on average, before giving again relevance to the visual portion of space where the red light appeared and orienting their gaze toward the danger signal. It is a considerable time within the RTs, which may cover one third of the whole reaction interval. Wasting it in a real hazardous situation could be vital.

Training it could quicken recognition and reaction times. Is it a trainable response? Yes, data show that it is vital to train to face different levels of unpredictability and different types of situations requiring an interaction.

Evaluate by feet

Behavior with pedals is not a simple automatism: there are at least 5 steps carried out for a complete articulation of the responses in 4 distinct types of motion behavior. The reaction time process answer does not lie just on the pressure on the brake, but it is composed of phases having their own specificity and partly serving the decision system.

Decision making process is continuous and steady. Deciding does not happen only in the beginning of the reaction interval as erroneously supposed in previous theoretical models. The influence of evaluation and decision making process related to the stimulus extends itself on the reaction times of all phases. The awareness of this possibility can avoid leaving the car to its own devices and carrying out every possibility of reaction-action until the last millisecond.

Results clearly show that the variation in reaction times apply mainly to the decision making phases (A-B) and not to motor execution phases of letting off gas (C-D) or pressure on the brake (E).

Variation of times depending on expectation are all determined by perception and evaluation of the situation by the subject, and are influenced coherently as psychological factors regulating perception, attention, emotional regulation and decision making vary.

In particular, results show that drivers do not exhibit any reaction at all if total mental workload, obtained by analyzing the situation, is incompatible with the expectations they build themselves. Time-to-collision (TTC) is not a factor per se: the experimental tests have been carried out in such a way that enough space and time existed to trigger and complete the subject's motor reaction. Actually when TTC has not been sufficient, it happens because the driver was not able to put into effect this motor reaction, in that she/he is busy to decide, instead to actuate a brake reaction as a primary and automatic response. Mental workload is also variable in time, but it has overall implications on the analysis process and on the response to stimuli.

Feedback and expertise for learning

Collected data highlight how there is no "absolute" learning effect (responding quicker to all the stimuli placed at the end of a session), but they seem to point out the existence of a particular learning effect bound to the initial lack of direct experience with the driving performance type used in this research. The drivers were instructed about the test execution, and that they had to respond to a red light which had appeared in front of them. The first time the event manifested, the drivers had reaction times longer than the average. When the same configuration showed up again, times decreased substantially, as the preceding experience allowed the driver to increase her/his ability to manage and coordinate the proper movements, making her/his behavior more effective.

After just one "test", the sample is able to improve the performance in such type of task, keeping the condition differences constant, regardless of the position in the sequence, provided that the subject have experienced at least once the "new" road situation typology which she/he has to respond to.

In effect, facing even just once a dangerous situation when driving, triggers a learning process which cannot substituted by a mere description of the same dangerous situation.

Also ECG data confirm how, during the test, less attentive and decisional resources are needed to deal with the driving response, both in normal situations, and during crucial moments when responding to environment road signs.

The parameters related to concentration and to physiological activity bound to the prefrontal cortex confirm that learning allows the subject to optimize her/his own resources and to perform a faster and more effective driving. The extent of this learning is evident also by analyzing the eyes movements and the portions of field of view which are monitored.

But, if cognitive interferences should manifest, again the activation and concentration level would increase, interfering with the driving task.

From these considerations, hence, arise the necessity to understand which are the actions and the stimuli of which at least one experience is needed. Not all subjects will respond the same way and to all situations, and not every situation needs the same response. The responses articulation in every phase and in every condition can be trained in order to actuate the best possible behaviors, being more aware of the different grades of danger predictability that can be met on the road. Moreover, the practical information related to the effectiveness of the actuated maneuver supply a feedback to drivers on their own or on the car's reaction times, in such a way that the response could be appropriate and effective to face the situation.

Hence it is important, for a driver to know how to read her/his own feedbacks in order to adopt the best driving maneuver in crucial situations. This can lead to a conscious learning of the specific maneuvers to be actuated as a response to different danger signals .

A training that would include some of the conditions herein used for research purpose, which change the alert grade in front of an unexpected event, can supply more correct skills and expectations to real dynamics which lead to a road accident.

Nevertheless, it must be considered that virtual trainings will be always different than the real world, maybe for different aspects than those herein described, but which might equally affect the results. The fact, for example, that emotional reactions in the virtual setting of the second study have been considered positive in case of accident or collision, leaves space for a series of questions that could be deepened starting from the conclusions coming from the second study, to better understand the implications on RTs.

6.2. Limitations

The present research is based on real results of drivers on a controlled track with no particular driving difficulty and with a constant and continuous driving task. These conditions have surely influenced the reaction times, since in the literature different weather-environment, track and traffic conditions has been proved able to affect RTs.

The stimuli proposed in the first study, used as a reference by the others, were generated by hand and also the throwing of the external object, although programmed through precise references on the track, is not uniform for all the drivers.

The sample can be widened to better control individual variance and the variance as a function of expectations. Using a different reference population could give particular information on particular records statistically more risky, like young adults or elderly drivers.

The same is true for the internal validity of studies that have used the other two simulators. In particular, it should be necessary to use an instrumentation more integrated with study 3 to be able to compare also the responses on pedals, beyond the GRT.

Moreover, it could be interesting to measure the legs' muscular activation, for the preemptive tension on legs (Kobiela F., 2010) to better study the effect of the expectations on the motor responses on the gas pedal.

Anyway, further test sessions are advisable to be able to produce an analysis that better considers the drivers typicality and the different driving contexts.

6.3. Practical outcomes

Through the collected data it is possible to find some interesting specific and practical indications, which could support road accident prevention trainings.

It should be advisable to study and to create devices that could improve the subjects' responses and their new supervisor role, to verify the impact of information that create incorrect expectations, which might be even more detrimental to avoid accidents.

It can be noted, indeed, the existence of a direct relationship between the stimulus predictability features, the perception and the decision taken times, and the modality of the related reactive action.

From an accident reconstruction point of view, it is possible to suggest information related to the type of situation the accident happened in: were some generic warning element, which could have alerted the driver, present?

Or the driver was in a condition in which the danger was not signaled, or, on the contrary, in which the driver can have been induced to think no danger was present?

Depending on how the reconstructed scene will look like, it will be advisable to calibrate the average time that could be used starting from possible brake marks present on the accident scene, and try to reconstruct the driver's reaction not using generic 1 second coefficients, but data like these, based on specific measurement of times related to the sighting and to the decision making process when driving.

In the same way, these new data could interest who design roads or manage public roads for a design that would take into account the human factor variability.

Also, it should be worthy to verify the effectiveness of prevention models that work on specific cognitive abilities, and to accurately quantify the drivers' learning responses.

From the point of view of who hold trainings, simulations, defensive driving and safe driving courses, what is interesting to note is not the driving skill, but the stimulus type, i.e. its significance, that the potential danger that the driver has to face, assumes.

Real or virtual training typologies could be created by which to try to train the responses to specific stimuli, which influence the drivers' expectations, to improve the effective responses to be actuated, until more conscious automatisms will be established.

Working on the interaction between different types of perceptions, decision making processes, motor actions, in specific tests with sudden dangers, better if faced for the first time, in virtual, as in non-virtual, conditions and facing them accurately.

As traffic psychologists, what can be said, perhaps, is that the current training offer lacks of exercises targeted toward the perception components and the decision making related to the expectations, which we have tried to outline by this particular research scheme. Moreover, the transition from the track, or from the simulator, to a real car, is not always tackled in a critical manner. Which and how many are the differences between training in the real world and through a simulator?

Is it possible to transfer the information and the skills acquired in a simulator, to the real world?

The implication of these answers is particularly interesting also for designers and producers of virtual reality systems and driving simulators, as well as for who manage driving fitness validations and are seeking diagnostic instruments with a proved and standardized validity when analyzing real world driving skills. A specific focus on reaction times could arise from such considerations.

Further studies, hence, could be started to build, to test and to spread instruments and trainings which should be scientifically approved and externally evaluated, in order to try to put the traffic psychology knowledge at the service of a concrete chance for effective road accidents prevention.

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