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Task-related fatigue: driving simulator experiments

Analisi degli effetti della fatica sul comportamento di guida.
Esperimenti in ambiente virtuale.

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"Fantasy is more important than knowledge,
because knowledge has its boundaries."

Albert Einstein

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Introduction

Driver fatigue is one of the major contributors to road crashes. According to the sub-categorization of the fatigue concept [1], this dissertation will examine the passive task-related effect of highway prolonged driving. Highway driving is an example of a monotonous driving environment that can increase the likelihood of accidents. The driving environment is relatively uneventful, predictable, and repetitive. While safe handling of a vehicle requires sustained attention, monotony leads to the opposite [2]. This factor, in particular, plays a fundamental role in arousal of passive task-related fatigue: situations of mental underload may lead to the driving task becomes automated.

Several countermeasures have been proposed to face the problem of driver fatigue, such as taking a nap, a cup of coffee, or other stimulants which have been proven effective, especially when sleep-deprived. Several studies have also dealt with the effectiveness of caffeinated chewing gum as countermeasure to fatigue for airplane pilot fatigue or on military task. This work is the first attempt to study its effectiveness as countermeasure to driving fatigue.

The main aims of this dissertation are to evaluate the best performance driving indicators, and to study the effect of caffeinated chewing gum as countermeasure to driving fatigue, with particular attention to passive task-related fatigued in non-sleep restricted condition. For this purposes, experiments using the driving simulator of Transport Research Laboratory of the University of Padova, have been carried out. The study has been conducted in cooperation with Bar-Ilan University (Ramat Gan, Israel).

Studies have been conducted to compare various caffeine dosages and modes of delivery (capsule, oral solution, gum) to determinate which

method is the safest, most reliable, and most rapidly absorbed. It was found that the use of chewing gum is the most effective due to its rapid rate of absorption [3]. It was found that the caffeinated chewing gum has quicker absorption rate in a faster reversal of the effects of fatigue compared to capsule.

From an operational point of view, the advantages of caffeine chewing gum are that it is small, portable, and convenient, does not need to be taken with liquid, and will be effective within 5 to 10 minutes.

The dissertation is organized as follows: Chapter 2 gives a whole definition of fatigue, the state of art and possible countermeasure; Chapter 3 describes driving simulator as research tool, advantages and disadvantages in using driving simulators and its possible application; Chapter 4 illustrates the laboratory apparatus, the experimental design, the case study analysis and results. Concluding remarks and future developments are presented in Chapter 5.

1 Road safety and fatigue state of the art

As known, a high number of accidents occurs on street caused by driving fatigue. Therefore, there is the exigency to understand the effect of fatigue on drivers' behavior to study strategy to mitigate the consequences.

1.1 Driving fatigue. General concepts

According to the dictionaries, fatigue in humans is so defined: "a cause of weariness; exertion: the fatigue of driving many hours". A comparison with definition of tiredness ("a need for sleep or rest") and sleepiness ("the state of being sleepy"), shows that fatigue is a unique way to describe a psychophysiological state that includes a part of both, but does not correspond to a specific one.

Furthermore, while sleep is presumably the best way to recover from sleepiness, from dictionary definition, it is not clear if sleep and rest are good remedy to fatigue.

It is important to discuss the fact that dictionary definitions actually reflect everyday usage, which often presents unclear concepts of terms like sleepiness, fatigue, tiredness or exertion.

Several definitions of fatigue in the literature are related to dictionary definition because it is described as a feeling, experience or an awareness similar to tiredness. However, definitions of fatigue, presented as an experience, have limitation. Firstly, they do not underline the importance

of fatigue effects, because the "feeling to be tired" could be the late stage in a process whose undesirable effects may have already compromised performance [4]. Secondly, people "living a fatigue experience" usually develop coping strategies for not worsening the level of performance, aiming to complete the task. Some examples of coping strategies developed by drivers are counting passing cars, driving waving on the lanes, or distracting in anyway. This can be considered as an additive cost in terms of increased effort and exhaustion [5]. In confirmation of this, Hockey measured subjective experience of fatigue and found that motivated people experience more fatigue than non-motivated ones. It implies that it is necessary to expand the concept of fatigue beyond mere experience in order to understand the dynamic role of exertion in fatigue. [6]

Another problem with existing definition is that they are associated with attempts to reserve the term of "fatigue" a meaning of extreme mental tiredness that affects (weakening and worsening) performance physical-task-related [7]. In addition to this definition, Hancock, underlines that: "as the muscle is the organ of physical action, so the brain is the organ of cognitive action and each similar response strategies" [8].

The difficulties of operationalizing fatigue as experience induced several authors to discard everyday usage of fatigue, in favor of definitions of fatigue as a physiological state of weakness resulting from exertion. One advantage of defining fatigue as a physiological condition is that it allows to use different measurement of different dimension helping to understand different aspects of fatigue; some methods imply the usage of electroencephalography (EEG), electrocardiography (ECG), electrooculography (EOG) or devices to measure percentage of eye closure or pupil dilation.

For example, electroencephalogram measures inhibition or excitement of postsynaptic potential of nerve cells at different frequencies: including delta waves, related to drowsiness, and theta waves, related to low wakefulness and cognitive process decrease [9].

In spite of the advantages, there are some negative expects to an exclusively physiological definition. Firstly, we need to include the experience of fatigue at the core of the definition: different physiological parameters may point out different level of fatigue in different subjects. Secondly, most operators never reach their own physiological limit of fatigue, even in heavy workload situation. Thus, it is fundamental

underline the importance of psychological factors in processing of fatigue [4].

Defining fatigue as performance impairment permits to use robust and objective measure in terms of safety behavior that makes fatigue as performance impairment definition particularly attractive to safety managers and researchers. However, no matter how much we are interested in performance, to ignore how people experience fatigue leads not only to face problems of validity, but also to an incomplete understanding of concept and its consequences: when fatigue is solely expressed in terms of performance decrement, the costs caused by coping strategies are not considered. These costs may be, in turn, cause of fatigue and worsen driving performance and, consequently, driving safety [7].

Another problem with solely performance definition is that frequently fatigue effects on performance are specific of the task: for example, they are linked to how and how much the operator forces to finish the task [10]. In an experiment by Hamelin, despite increased reports of fatigue in prolonged driving tasks (11 hours), the effects on safety performance are not as relevant [11].

That being so, it is clear that representing fatigue in terms of solely performance is inadequate, and that any definition of fatigue should explicit the role of the nature of the fatigue, related to the specific task, as well as the value of level of performance of the operator.

Problems of definition based exclusively on selected dimensions of fatigue are highlighted not least by studies showing dissociation between experiential, physiological and performance indicators of fatigue. For example, a study by Craig et al shows a difference between self-perception of fatigue and physiological measure [12].

Finally, we can conclude that: the failure of defining fatigue only looking at one aspect of it is clear. It limits the concept of fatigue which is vary and multifaceted. These attempts guide to definition considered as incomplete or not satisfying by researchers interested by other aspects of fatigue.

1.1.1 Fatigue, exertion and drowsiness

Exertion has been an important aspect of the concept of fatigue. Despite there is no definitions of fatigue as exertion and its relationship with fatigue, the first approach in that direction has been taken by Desmon and Hancock (2001). In their study, they first put a distinction between "passive" and "active" fatigue task related (par. 1.1.2). Active fatigue is described as the kind of fatigue due to exertion from overload in high-demand driving condition, where there may be dense traffic, time pressure, and other tasks besides the main driving task. Passive fatigue is due to exertion from having to perform in under-load conditions , i.e. low-demand condition such as monotonous driving tasks. The concepts of active and passive fatigue is fundamental for this thesis and will be well illustrated in chapter 1.1.2, going through the definition scored by May and Baldwin [1].

A complete definition of fatigue needs a priori knowledge of the level of exertion, independently from the cause. Many studies have been done in this direction and all of them demonstrated that factor such as state of health, habits and to be hungry or not, may influence the self-perceived level of fatigue, and so, the driving performance. Otherwise, individual differences, external environment or psychological differences may influence the level of fatigue and performance ([13], [14], [15]). These works find that exertion required to achieve the same level of performance using the same strategy is greater when one is hungry or thirsty, in a non-optimal condition, or experiencing extreme ambient conditions. Every single factor may contributes to the level of fatigue in drivers. While the real exertion causes fatigue, surrounding conditions contribute to increase fatigue for a given level of performance, by increasing the level of exertion.

According to the two-process model of sleep, sleepiness is caused by the effects of homeostatic factors that increase through the day from the morning, and circadian factors, which are especially involved in increasing sleepiness in the morning and in after-lunch-time. Studies about the effects of sleep loss or forcing the desynchronization of circadian period, showed how these factors influence the perception of sleepiness and mental performance [14]. A specific study about sleepiness showed that it could impair driving performance [16].

Despite some authors initially used fatigue and sleepiness as synonymous, there are two good reasons to distinguish fatigue from

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sleepiness: there is the evidence that when assisted by robustly operationalized measures, not only people can clearly distinguish between fatigue and sleepiness, but also fatigue may be more prevalent. Secondly, several studies suggest that sleepiness alone fails to explain all of the important performance effects related to tiredness.

In an article, Williamson asserts: "the most obvious for cash rate peaks around midnight would appear to be that the trends in risk are confounded by differences in other factors that contribute to overall fatigue".

We can conclude that it is not possible to clearly limit concepts of fatigue and sleepiness. To be able to consider the effect of the sleepiness on driving performance, further research should clear out the role of sleepiness in relation to the concept of fatigue.

1.1.2 Sleep-related and task-related fatigue

Conceptualizing fatigue in transport safety context, it is important to underline that fatigue may occur as a resultant of many factors: sleep loss, circadian period, the driving task or a stressful environment.

In identifying factors inducing fatigue, to distinguish fatigue sleep-related and task-related is as important as difficult. In real life, these both effects obviously interact, in research it is fundamental separate them.

In a study on the importance of identifying causes of fatigue by May, sleep-related fatigue and task-related fatigue are presented as follows.

Sleep-related fatigue is caused by circadian rhythms, sleep deprivation and sleep restriction. Sleep/wake patterns follow the body's natural circadian rhythm, which drives humans to sleep during the night and be awake during the day. The circadian rhythm also produces an alertness dip in the early afternoon during which people are sleepier.

Circadian effects on driving performance have mostly been studied using driving simulators. For example, a study by Lenne shows how sleep deprivation has bad influence on driving performance, considering the time of the day [17].

In a study about driving fatigue caused by partial sleep deprivation by Philip et al, volunteers were asked to drive 5 times on a 200 km circuit with light traffic and different level of previous rest and in different

moments of the day. After each driving session, participants had to complete subjective sleepiness scales and a 10 minutes reaction time test. Number of crossing line was used as performance indicator. Study demonstrates that all the indicators worsen during the driving test and level of sleep deprivation was more significant than the time of driving.

Several studies about fatigue effects on driving require tester to perform driving task during monotonous highway condition on sleep deprivation: this may confound the effects of sleep-related and task-related fatigue, but sometimes it is about inevitable.

Task-related fatigue is caused by driving task and driving environment. It can be considered active or passive fatigue. Active fatigue is the most common form of task related fatigue that drivers experience [18]: it is caused by driving situation inducing a mental overload, e.g. intense traffic, low visibility, or the need to complete a secondary task in addition to the main driving task.

Passive-task related fatigue, on the contrary, is produced by a too low level of mental demand, in condition of monotonous driving where the only task is simply to drive and monitor an eternal environment without any stimulus. Passive fatigue occurs when the driving task is predictable.

In a study on the effect of passive task-related fatigue, Rossi et al. have found bad influence on driving performance of circadian rhythm, length of driving task, monotony of the environment. Most relevant effect encountered was time effect, followed by time of the day and monotony effects [19].
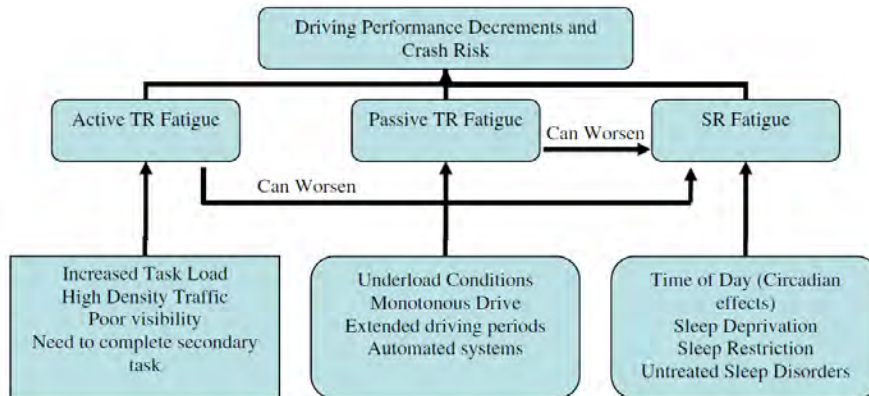
Figure 1: sleep-related e task-related fatigue. Source: [1]

Despite sleep-related and task-related fatigue seem to produce the same performance decrements, May and Baldwin underline the importance to identify causes inducing fatigue with the aim to elaborate countermeasure to fatigue [1]. Devices for detecting driver fatigue may be effective for both types of fatigue, but countermeasures will only be effective in relation to principal causes. In addition, concerning task-related fatigue, it is fundamental to distinguish between active and passive fatigue. For example, adding a new secondary task to main driving task may improve the performance during passive fatigue, but it could have the opposite effects on active fatigue. In the following section (1.2) main technological countermeasures will be presented.

Drivers can be categorized in groups: in this section, groups are those that have been presented in the literature and they reflect those identified internationally as the higher-risk groups. The first distinction we can make is between "transport groups" and "demographic groups".

Transport groups:

Commercial motor vehicle/driver fatigue and alertness study (1996) noted that commercial drivers generally worked on limited sleep, reveal chronic fatigue clearly linked to nighttime circadian effects, and they were untrustworthy judges of fatigue levels.

We can distinguish five driver groups presented in literature:

- drivers of trucks and heavy commercial transport vehicles;

- bus/coach drivers;

- shift workers;

- commuters.

Demographic groups:

Generally, it is possible to identify four demographic groups:

- young drivers;

- old drivers;

- tourist drivers;

- other drivers.

It is important to categorize the driver groups both to select the most effective type of countermeasure to fatigue and how it can start growing during a driving task. Many studies have shown differences in driving behavior and coping strategies for fatigue between different age groups [20]. Other studies investigated time distribution of road accidents and the role of sleep-related fatigue. [21] showed the effect of sleepiness on a specific category of shift workers: he investigated the role of sleep-related fatigue on policemen with reference to different working rotation shifts covering the day.

Accidents caused by drivers falling asleep are likely to be fatal or involve serious injuries because a sleep driver does not make any corrective actions and the impact speed can be high. An uncontrolled vehicle driven by a sleeping subject continues moving and might cross the middle line or drift off the side of the road. Most of the accidents caused by driver falling asleep are head-on collision, running off the lane, and less often rear-end crashes.

If a driver wakes up before possible impact, he acts in panic by applying a sudden corrective movement. As a result, a crash might be inevitable. In a similar way, in a driving simulator study by Thieffault & Bergeron, fatigued drivers, compared to rested drivers, make corrective steering wheel movements, but when they do, the movement are higher of amplitude [2]. These larger corrective movements are necessary because fatigue drivers usually have problems keeping car within the lines; as results, "there are more line crossing and a higher standard deviation of lateral position" [22].

Therefore, fatigued or sleepy drivers do not need to fall asleep to have an accident; they just may fail to perceive the correct position of their vehicle on the road.

There are many factors that increase the level of sleepiness and sleep-related fatigue, contributing to be the cause of crash due to falling asleep inattention. Circadian variation is a major cause of sleep-related accidents. During the night humans have the highest need for sleep, so, this is when many sleep-related accidents occur. Many studies have shown a clear time-of-day pattern of sleep-related accidents [23].

Alertness at any point of time is not determined only by circadian factors, but it also depends on other variable alternation of sleep and wakefulness. The duration of wakefulness and sleep, time on task, and circadian effects are intertwined. A study by Williamson & Feyer showed

how 17-19 hours of wakefulness produce performance decrements equivalent to those observed at 0.05% of blood alcohol concentration.

Driving duration has been regarded for a long time as one of the most important risk factor for falling asleep. However, driving duration alone does not seem to be crucial factor, indeed most of fatal sleep-related accidents occurs within the first hour of driving.

1.2 Countermeasures for driving fatigue

Seeing as of sleep related accidents are characterized by behavior of the drivers, generally, two types of countermeasures can be identified: technological countermeasures and non-technological countermeasures. Another secondary distinction in countermeasures for driving fatigue can be those applied by drivers themselves and those designed by industry society.

1.2.1 Technological countermeasures

Detection and warning technologies use measure that are sensitive to physiological and fatigue related performance changes such as eye movements and closure, head-nodding and steering corrections. The aim of these tools is to warn the drivers against their fatigue state, so they can stop and take countermeasure. Since these technologies seem to be more inclined to recognize sudden-onset sleep, it seems they are more effective for sleep-related fatigue.

Eye closure:

Technologies such as PERCLOS system are able to compute the eyelid closure over the pupil by video monitoring the eyes. It calculates an index of fatigue by measuring this in about one minute intervals. In particular: the algorithm computes the percentage of time per interval that the eyelid covers the 80% of the pupil. This technology has been validated by driving simulator studies and in real world driving too. Results of these technologies have been compared to EEG's, eye blink software, and head-nodding technology: PERCLOS technology is more effective in detecting fatigue than the other previous technologies.

Figure 2: PERCLOS technology working scheme. Source: [24]

<u>*Head-nodding technology*</u>:

Everyone has experienced once in life the consequence of falling asleep in seated position: the head start nodding because of muscles relax. Technology as No-NAP fits over the driver's head and monitors its position. As the head nods, No-NAP system produces a buzz in order to wake the driver up.

Other technologies such as Dozer's Alarm and micro-nod detection have been tested in a couple of studies by using a driving simulator during a driving task at night ([25], [26]). Results showed that the alarm did not improve lane-tracking performance and did not allow drivers to maintain alertness, but it worked well for drowsiness detection. Thus, the head-nod technology warns drivers too late as to their sleepiness.

<u>*Crash prevention technology*</u>:

Despite crash prevention technologies were designed to prevent crashes regardless of the causal factors, most of incidents result from running off the road. This is a typical characteristic of fatigue-related crashes.

Crash prevention technology can be categorized as follows:

- Roadway designs: for example, rumble strips are a roadway design option for monitoring weaving and alerting drivers when they drive off the road;

- Lane departure warning systems: lane drifting or departure technology receives information from a video that monitors the road ahead and graphs the boundaries of the lane. An alarm sounds when a driver veers out of the lane;

- Collision avoidance systems (CAS): they are integrated in some vehicles and they aim to alert drivers of potential rear-end or from the side crashes. CAS can measure the headway or the time to collision.

Technology designed to reduce fatigue is appropriate for drivers experiencing task-related fatigue. Technological countermeasures intend to increase stimulus to prevent passive task-related fatigue or include vehicle automation to reduce task load for active fatigue.

Interactive technology:

Studies proved that giving drivers secondary task to perform during primary driving task when fatigue start coming, would increase their alertness. In particular, Varwey and Zaidel (1999) studied the effect of a game box called "Car Mate" that was a verbal interface designed to allow the driver to play 12 different games. The results were that drivers who used Car Mate produced lesser decline in vehicle control and fewer incidents. Self-reported level of fatigue and drowsiness were fewer in game box condition [27].

Another technology is the "Interactive Knight-Warrior Sleep alarm" which periodically emits an alarm at a fixed time interval. Drivers have about 3 seconds to stop the alarm; otherwise, a secondary louder alarm will sound to wake up the driver.

Automation technology:

Automation technology aims to transfer control of the system from the driver to the vehicle. For example, using cruise-control technology, task as speed control is transferred from driver to the vehicle. A study on task-related fatigue by Funke et al. shows that lane keeping performance is improved by the use of cruise control [28]. The purpose of adaptive automation is to modify the task load depending on the driver's state.

Examples of automation technology are the S.A.M.G-3, steering attention monitor (Electronic Safety Products). It monitors corrective

steering movements, it defines micro-correction that drivers usually do to maintain performance. An alarm sounds when normal steering increases. The SAVE system integrates a monitor unit, a warning system and an automatic control device. It detects fatigue or unresponsive driver and, if the driver is not responding, it stops the car on the side of the road.

In conclusion, we can assert that technological countermeasures to fatigue must distinguish between different forms of fatigue: countermeasures will be more or less effective depending on the kind of fatigue the driver is experiencing [1].

1.2.2 Non-technological countermeasures

It is possible to define two categories of non-technological countermeasures for driving fatigue: *preventive countermeasures* and *operational countermeasures*.

Preventive countermeasures are meant to be used before duty and during rest periods. They are designed to minimize sleep loss and reduce disruption to circadian cycles. These may work to prevent fatigue.

<u>Sleep loss minimization</u>: the effect of sleep loss is cumulative and reduction of this loss is critical to safe and efficient operation.

<u>Naps</u>: naps can improve alertness. Many studies demonstrate the effectiveness of taking a nap both before driving and during rest period in driving ([29], [21]). Researchers assert that the second best countermeasure for the problem of driving fatigue after prevention is napping. There are different opinions about the optimum nap period for improving alertness, but what is clear is that sleep is the cure for sleepiness, it is far better to take a short (10-15 min) nap if possible [29]. Longer naps could develop into a full sleep, so causing difficulty in arousing and be counterproductive initially.

<u>Good sleep habits</u>: the best way to combat sleep-related fatigue is to have good sleep habits. Eating a big meal before bed, utilizing caffeine, alcohol and nicotine in addition to adverse environmental conditions all interfere with good sleep patterns. Rest period must be a priority and should be kept free from other commitments and activities.

Operational countermeasures are meant to enhance alertness and performance. Most common operational countermeasures do not actually work, for example it is common to think opening car windows or turning up the radio improve alertness and impair fatigue; they can work for just few minutes, but this temporary benefit may provide enough time for the driver to locate and stop at a suitable place to park and rest.

Another methods are to take a walk or some physical exercise during a break from driving, but, again, they may work for only few minutes [30].

Caffeine (as in coffee or energy drink) is probably the best choice. Caffeine taken in this manner requires about 30 minutes to become effective, and the beneficial effect lasts about an hour. Many studies have been done about the effects of caffeine on driving fatigue and will be further presented.

1.2.3 Caffeine as fatigue countermeasure

It is important, considering the topic of this thesis, to dedicate a particular paragraph to the caffeine and its effect. Caffeine is probably the most used legal stimulant. It is typically consumed as coffee, and one cup usually contains 80 mg of caffeine. Caffeine has effects on the central nervous system, particularly on the adenosine receptors. Adenosine is a potent sleep supporter.

There are some issues associated with research investigating the effects of caffeine. The use of caffeine in studies is not very consistent: there are variations in the duration of abstinence, size of dosage (typically 120 mg/150 mg), kind of administration. Also, many different performance measures have been used.

The effect of caffeine on performance is still questionable. Several studies have investigated the effects of caffeine on different performance parameters that are related to driving task. A study [31] showed that a considerable dose of caffeine (350 mg) can reduce sleepiness in drivers deprived of sleep, and have not effect on non-sleep deprived ones.

While caffeine has been found improve alertness and have positive effects on information processing and cognitive performance, some studies have shown that when fatigued, caffeine does not improve temporal memory and motor performance of people. Caffeine improves vigilance performance and

prevents decreases in alertness, and the size of the effect increases with caffeine dose in nighttime administration.

Regarding the caffeine dosage, a study demonstrated that caffeine has the same effect when consumed in one large dose compared to a realistic regime of caffeine consumption of many smaller doses [32]. The authors ensured that the amount of smaller doses was exactly the same of the bigger one. Caffeine improved driving performance, cognitive vigilance task and increased alertness.

Resuming, empirical results show caffeine improves alertness and driving performance when a driver is fatigued, in particular when fatigue comes from a sleep deprivation status. Obviously, there are very few studies evaluating the effects of caffeine on sleep deprived or fatigued drivers in real driving situation:driving simulators provide another way to investigate on caffeine effectiveness as countermeasure to fatigue.

Apart from coffee, caffeine is available in other beverage and slow-release forms. For example, energy drinks, caffeine chewing gum or caffeine tablets.

Energy drinks are nowadays as popular as coffee as caffeine source. A study showed the positive effects of Red Bull® Energy Drink on driving performance [33]. Under similar experimental conditions, a study by Reyner and Horne found that the same energy drink had benefits in reducing sleep-related driving incidents and subjective sleepiness during the afternoon for the first 90 minutes of a simulated drive. They found energy drinks may be more effective as countermeasure to sleepiness than caffeine consumed as coffee [34].

Many studies have been done on the comparison between caffeine and napping. A study by Bonnett et al. demonstrates that consuming 150 - 300 mg of caffeine has about the same effect of two - four hour naps on sleep-deprived subjects. The most important finding of this study was that a long sleep (8 hours) is better in maintaining performance and alertness than repeated shorter naps or repeated doses of caffeine [35].

Horne and Reyner conducted some studies about the effects of naps versus caffeine. In particular, in their 1996 study they examined the effects of caffeine (150 mg, 2 cups of coffee) and a short nap (about 15 minutes) taken during a two hour driving task in a driving simulator. Volunteers were partially sleep deprived. Caffeine and napping both reduced sleepiness

in sleep deprived subjects [23]. A second study conducted in 1997, examined the effect of caffeine (200 mg) versus caffeine (150 mg) plus 15 minutes nap taken during a 30 minutes break before a two hours driving task on a simulator. The combination of caffeine and nap was better than caffeine alone in terms of performance.

Concluding, caffeine is a widely available mild stimulant that is safe to consume at moderate levels. Empirical evidences indicate that relatively low doses of caffeine (100-150 mg of caffeine) improve alertness, cognitive performance and reduce driving incidents on driving simulators. The studies showed that drinking caffeine promotes alertness and improves driving skills on sleep deprived drivers, but combination of a short nap and drinking coffee appears to be more beneficial. However, these benefits are only temporary; they dissipate in about two hours. Thus, caffeine and naps cannot substitute a long sleep; they only delay the effects of sleep-related driving fatigue.

The main target of this thesis is to examine on the effectiveness of the usage of caffeine chewing gum for reducing driving fatigue, by means of driving simulator experiments. Therefore, it seems interesting to present, in detail, some similar previous studies.

Effects of coffee on driving performance during prolonged simulated highway driving [36]

In a study by Mets et al. twenty-four healthy, non smoker, and moderate caffeine drinker (two or three cups a day) volunteers (12 males and 12 females) were asked to drive for four hours. A 120-minute drive in simulator was conducted and after that, in a 15-minute break, subjects received the treatment. Every hour the volunteers had to fill-in a questionnaire about their perceived level of sleepiness (Karolinska Sleepiness Scale, KSS).

Participants, during the break, took or an espresso coffee, containing 80 mg of caffeine, or a placebo (decaffeinated coffee).

Standard deviation of lateral position (SDLP) and standard deviation of speed (SDS) were chosen as performance indicators. The order of the trials was randomized. Every test was conducted at the same time of the day to prevent effect of circadian period.
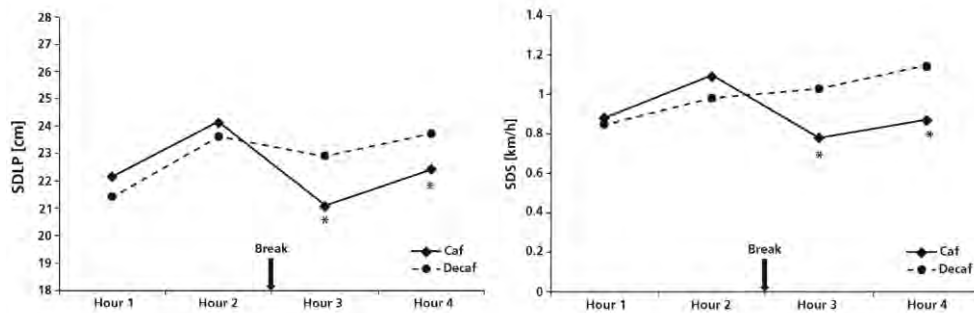
Figure 3: Standard deviation of lateral position (SDLP) and standard deviation of speed (SDS). Source: [36]

The study demonstrates that one cup of coffee (80 mg caffeine) improves driving performance and reduces driver sleepiness. Both lane keeping and speed maintenance improved. The time duration (about 2 hours after coffee consumption) and magnitude of effects, , were comparable to the results obtained in a driving study with Red Bull Energy Drink using the same design and driving test [33].

In conclusion, this study demonstrates for the first time that one cup of coffee has positive effect on healthy volunteers with reference to continuous highway driving task. Older studies only considered higher caffeine doses (i.e. 150 mg to 350 mg) that are not usually consumed by drivers in real life.

The effects of caffeine on simulated driving, subjective alertness and sustained attention [37]

A study by Brice and Smith examined the effects of caffeine on a computerized performance task and on simulated driving performance on non-fatigued volunteers, as opposed to the effect of caffeine on driving performance on fatigued drivers studied in a previous work [29].

Twenty-four non-smoker healthy participants were recruited. Each participant took part in four test sessions on separate days: two sessions of driving task and two sessions of computer tasks. Each participant received 3mg/kg caffeine or a placebo for both task Participants had, also, to fill-in a questionnaire about sleeping habits over the previous days and hours. Volunteers then performed for 1 hour on driving task. On completion of the first session participants consumed the beverage. After 30 minutes participants returned to the simulator and completed the second one-hour-driving test. Standard deviation of steering angle and edge violations (kerb hit) were chosen as driving performance indicators.

In different days, volunteers were asked to do a performance-repeated digits detection task with the same design of the driving task. This is a visual cognitive vigilance task with a low frequency signal detection and a high-frequency event rate. The task lasted 3 minutes that is enough to detect a decline in performance on task. The number of hits and false alarms and reaction time were recorded as alertness performance indicators.

A significant effect of caffeine was found for the measure of alertness. A significant interaction between task type and caffeine condition was also identified.

In the vigilance task a main effect of caffeine on a measure of accuracy was found, not in the reaction time.

The results on driving performance were interesting: no effect of caffeine was found in hitting kerbs, but a significant increase of accuracy after caffeine consumption was shown. Surprisingly, there was no interaction between time on task and caffeine. In their discussion authors demonstrated the beneficial effects of caffeine when fatigue is induced by a monotonous task. Despite that, they underlined that the effect of caffeine on steering variability did not vary with time on task maybe because steering variability is not a good indicator of fatigue.

2 Driving simulator in road safety research

Driving simulators are nowadays one of the most largely used tools for research in driving behavior and performance. Looking at the major journals – e.g. Transportation Research Part F and human Factors -, it can be noticed that most of the studies in driving behavior domain is based on driving simulators use. In 2009, for example, 32% of the papers published by Transportation Research Part F, was based on experimental studies implying the use of driving simulator.

Driving simulators are used for:

- experimental manipulations;

- evaluating effectiveness of different treatments;

- what-if scenarios in relation of new technologies;

- evaluation on impairing effects caused by fatigue, distraction or alcohol or drug intake.

2.1 Classification of driving simulator

It is not possible to give a clear and univocal definition of what a driving simulator is. Driving simulator configuration can vary from a simple joystick controller, in a simplified environment with only one PC screen, to a huge and expensive laboratory provided by whole vehicle mounted on motion systems with more than 9 degrees of freedom and field of view of 360°.

What we can say is that a simulator generally includes :

- one or more screens where virtual environment is projected;

- vehicle controls: the minimum is a joystick, but usually a full vehicle controls configuration;

- one sound system to replicate vehicle and traffic noise;

- one dashboard: it can be real or a virtual dashboard.

Currently, driving simulators' graphical component is generated by a real-time animation in one or more screens, but before the modern PCs coming, driving simulator was made by a miniature vehicle rolling on a road, reproducing a highway layout. A driving simulator of this kind was used by Mortimer to study the effects of alcohol intake on driving performance [38].

The approach for modern simulation is to apply real-time graphic image generation. It implies much flexibility in terms of scenes that can be displayed, within the typical limitation of projectors and monitors. Indeed, monitors have intrinsic limitation of definition and brightness, and they cannot simulate the halo effect of nighttime glare or similar.

According to Weir and Clarke [3], driving simulators are commonly classified into three categories: high-level, mid-level and low-level.

Low-level simulators:

They are usually composed by one PC for graphical rendering, creation of the vehicular traffic and simulator control. They are cheap both for the development and maintenance. Because of these peculiarities, low-level simulators can also be adopted by driving school for first driving practices.

Mid-level simulators:

These driving simulators are more advanced and expensive than low-level simulators. Thus, they are used as research tools. A network of several PCs composes them and they have more than one display. Generally, motion system is not included and, if it is, it is a low-quality motion platform.

<u>High-level simulators:</u>

These simulators usually have a 360° field of view and advanced motion systems (with more than 9 degrees of freedom).

Obviously high-level driving simulators are more expensive than mid-level and low-level ones. Of course high-level simulators are not always needed: a low-mid-level simulator can be as reliable as a high-level one for some kind of study.

There are several motivations pushing researchers in the direction of using driving simulators. The main incentive is represented by the possibility to control instant by instant the driver behavior and create repeatable scenarios and situations.

Furthermore, costs of a laboratory study are far less than the same study in real-driving environment. Lastly, using a driving simulator, it is possible to reproduce risky driving situation that cannot be replicated in real-driving environment.

Summarizing, application of driving simulators are several, in particular:

- Introduction of new technology in-car for driving support;

- New road design;

- Studies of the effects of new infrastructures or new traffic regulations;

- Studies of the effects on driving safety of fatigue or sleep loss;

- Studies of the effects on driving safety of drugs or alcohol intake.

One of the most debated topic about the validation of driving simulator experimental design is represented by the use a motion system: how much is desirable the vehicular dynamism, and what kind of platform should be used?

Several studies demonstrate that driving behavior became more realistic as the dynamic feedback of the vehicle improves (i.e. [6], [40]).

Nevertheless, independently on the level of motion system technology, it is not easy to simulate the effects of lateral acceleration perceived by a driver in real-world situation.

The choice of the simulator

The most obvious answer is always to use the best driving simulator - the most technologically advanced one- able to reproduce in the best way a real-world-driving feedback. Unfortunately, because of the cost, it is not always possible.

Nevertheless, motion system is not the only factor weighing on the quality of the driving simulator.

Other important features are:

- parameters of the screens: field of view, pixel density, brightness and contrast;

- delay: delay between driver's input and reproduction on the system;

- scene animation: complexity and reality of the virtual environment;

- physical model adopted to compute vehicular dynamisms;

- vehicle interface;

- sound system in terms of software and hardware.

Every simulator, as much as technologically advanced, presents limitation considering at least one of the previous features.

2.2 Validation of driving simulator as a research tool

The validity of the use of driving simulator as research tool is highly debated . Simulators are largely used as training tools in aviation and navy. Generally, in these fields the use of simulators for training is valid considering the high cost (and high risks) of real-flying or real-sailing situation.

In driving field, simulators have mostly been used as research tools.

Physical validation of driving simulators, and consequently the validation of the experiments, can be subdivided in different components:

- Accuracy in vehicular dynamisms;

- Capability of the systems to reproduce the reality, in terms of brightness, contrast, resolution, field of view and perception of dimension of virtual environment;

- Realism of sound effects;

- Realism of the control elements of the vehicle that can influence the interaction between vehicle and driver (kind of pedal-board, steering wheel, gearshift and speed of broadcasting signals from these control elements and simulation process);

- In a dynamic simulator, the number of degrees of freedom of the motion system and inertia and mechanical delay of input-output gearbox.

Another problem about the validity of driving simulator as research tool is that, dislike to flying simulators, there are not standards for evaluating tests.

The validation topic is also about the experimental design. In fact, no particular experimental design can be considered as standard, but within-subject designs are more powerful and so largely used. However repeated measures also have some disadvantages in terms of time and because they induce familiarity with the scenario of the experiment. In the same way, counterbalanced trials should be considered norm for masking learning effect. On the other hand, balancing makes difficult to evaluate learning and ordering effects when they are important. Thus, we can conclude that: there is no right experimental design or wrong experimental design, and only empirical experience can help to choose the best one.

Simulator sickness

One of the most relevant problems noticed in driving simulator experiments is the "simulator sickness". The sickness is linked to motion: it is caused by the offset of visual perception of the acceleration (or

deceleration) and the feeling of movement linked to the vestibular apparatus. Of course, there is not any vestibular feedback in static driving simulators, but advanced motion technologies are also a bit different to real-world driving behaviors: the consequence is that there is the possibility of onset of symptoms of "simulator sickness".

Simulator sickness is more than just an inconvenience [41]. In a study, Bitter at al, confirmed an interaction between age and uprising of simulator sickness. Then they find out that simulator sickness affects performance in the emergency task, so they strongly recommended that researchers explore the potential confounding effects of simulator sickness to guarantee meaningful performance evaluation.

2.2.1 Traffic data: measures and parameters

Traffic flow, typical of road systems, is a complex system dependent on several factors. Thus, in field of safety transport research there is the need to describe the system in high detail, analyzing the different components making the whole system.

The traffic system may be described by three components: the driver, the vehicle and the road. The interaction among these three components are equally important.
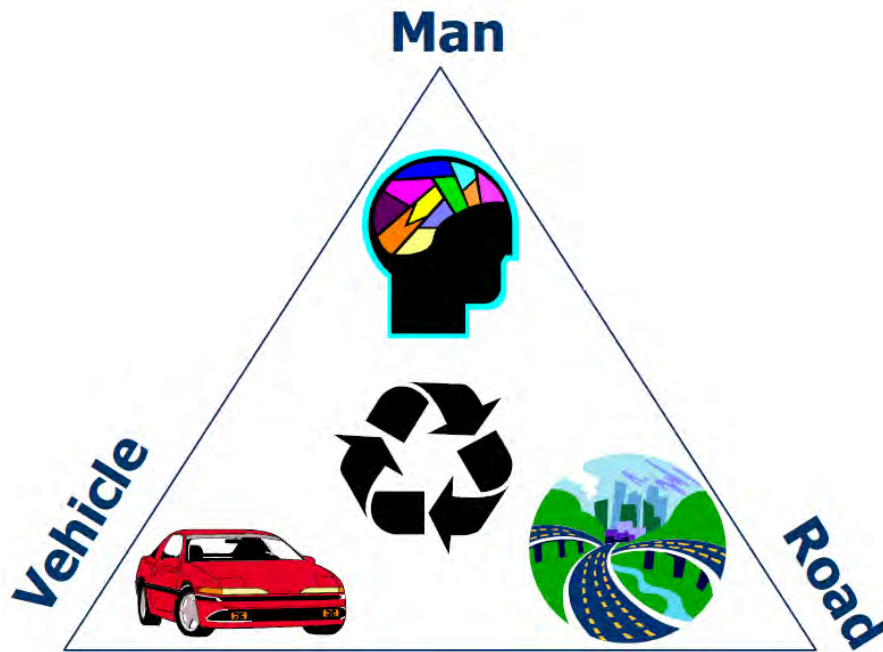
Figure 4: the interaction among the driver, the vehicle and the road. Source: [42]

Driving simulator can be used to study all the three factors and their interactions.

In particular, the effects of these interactions can be represented by measuring some parameters that can vary on the target of the study.

Looking at the literature, the most important parameters are:

- speed;

- time to collision (TTC);

- headway and gap;

- brake time reaction;

- lateral position;

- time to intersection;

- steering-wheel angle;

- steering-wheel error.

In chapter 3.1.1, parameters of Transport Research Laboratory's driving simulator at the Department of Civil engineering of Padua, will be listed and described.

Many data about physiological state of the driver can also be collected, for example:

- heart rate;

- skin conductivity;

- cerebral work load activity (EEG).

Cognitive information are also relevant. They can help to describe mental and physical workload perceived by the driver. In particular, it is possible to recognize four categories of workload parameters:

- subjective perception of workload level;

- performance indicators;

- physiological measures.

In literature, we can find many examples of methods that can be used to collect cognitive information: sometimes, more than one parameters are measured, so researchers can compare them to evaluate data reliability.

For example, Kirker [43], aiming at recognizing the best drowsiness indicator, measured cerebral workload (using EEG) and eye blinking. Number of crossing lane and standard deviation of lateral position were used as performance-drivers indicators. Thus, Kirker aimed to correlate physiological and performance parameters.

In a study about the effect of coffee on driving performance during prolonged simulated highway driving [36], standard deviation of lateral position and standard deviation of speed were used as indicators of driving performance. At the same time, volunteers were asked to fill out questionnaires about self-reported, subjective level of drowsiness (Karolinska Sleepiness Test, KSS) and self-reported level of perceived fatigue (Visual Analog Scale, VAS).

Many other papers similar to the previous ones are present in literature.

2.3 Driving simulator for fatigue evaluation

As previously seen, driving simulator can be considered an efficient option to real-world tests. Nothing has been told about driving simulators as research tools in driving fatigue research.

As presented in a study on healthy young man, combination of sleep loss and prolonged driving session has bad influence on driving performance [22]. Similarly, a study by Banks at al (2005) for the first time deduced the evidence of predictive measures as objective parameters of drowsiness for driving performance in a simulated environment [44].

Contardi et al. showed the validity of a simulated environment and monotonous driving task for the evaluation of circadian rhythm on healthy subjects (sleep disorder affected not allowed) [45].

Thus, fatigue and drowsiness effects can be well analyzed by using a driving simulator, despite more "driving errors" have been noticed than real-world driving situation. From literature [46] we can also conclude that driving simulator is a good choice to measure the worsening of driving performance caused by long driving sessions: despite driving simulator induces drivers to increase number of "driving errors" and, due to that, it overrates fatigue index, self-reported index of fatigue is exactly the same in both simulated environment and real-world situation.

In a study about development of driving fatigue symptoms during simulated driving task [47], 80 volunteers were asked to drive until they were too sleepy to drive. Every 20 minutes they were told to verbally define their level of fatigue. The results were clear: the desertion always corresponded to the highest self-perceive level of fatigue. *Figure 5* represents an objective measure of fatigue development on time.
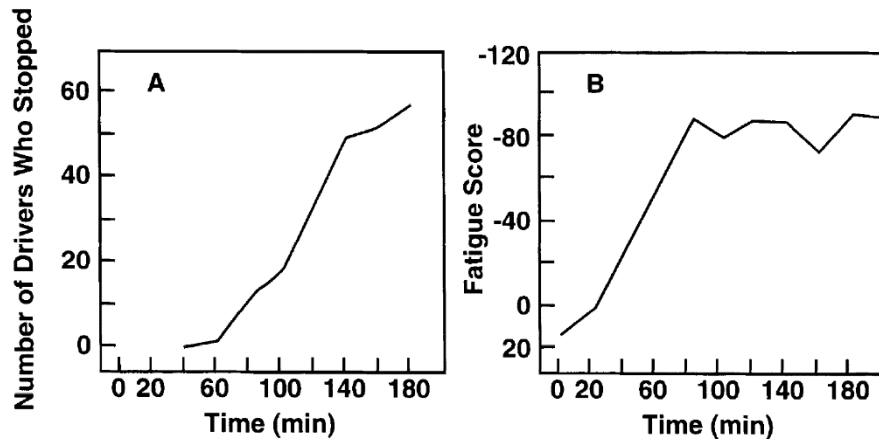
Figure 5: fatigue development in Nillson et al. (1997) study. (A) Number of subjects that have deserted the test vs time. (B) Self-reported level of fatigue vs time. Source: [47]

As far as technologically advanced, a driving simulator will always be different to a real-driving situation. Therefore, it is necessary to consider a leaning time: data from driving simulator experiments cannot be considered reliable if driver did not become familiar with simulated-world situation.

Consequence to the non-adaptation obviously is a bigger variability of driving parameters (lateral position, speed, etc.), thus there is the necessity of a complete adaptation to the simulator to have the data to be completely valid and reliable [48]. In this study, by McGhee et al., the aim was to find the adaptation time at the steering wheel of a driving simulator: standard deviation of lateral position and standard deviation of steering wheel angle were used as indicators. The volunteers were divided into two groups: one composed by young healthy people and the other old healthy ones. Contrary to what expected, no difference came up between adaptation times of the groups. Authors underline how adaptation time is influenced by cognitive task the driver is subjected.

In another study concerning adaptation period on driving simulators [20], authors found that even if driving simulator is a low-level simulator drivers transfer their skills after some adaptation period. Therefore, they do behave like in real-world situation. In this study, volunteers were told to drive in different scenarios in the same time slot to reduce the circadian-rhythm effect. The result was that different scenarios have different adaptation time: in particular, monotonous straight scenario had 6.3 minutes as adaptation time, similarly as previously found by McGehee (2004). In a curvy and windy scenario, for example, adaptation time resulted to be about double to the previous (11.3 minutes).

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In conclusion, of this chapter, we can resume that simulators provide the opportunity to investigate driving tasks under controlled conditions. They offer some advantages against the real-life situation: the possibility to create a repeatable scenario and the opportunity to control experimental conditions. The number of driving simulator experiments per year continues to increase, as well as the scientific papers on driving performance and behavior analysis.

3 Case study

The complex nature of fatigue and sleepiness has attracted multidisciplinary and interdisciplinary studies with various methodologies and study designs. Indeed, psychologists, physiologists, engineers and ergonomists all have contributed with their own methods. Experimental and laboratory studies, including driving simulator and on-road studies, questionnaires, analyses of accident statistics, have provided a wide range of variable results.

As in any scientific research, this thesis follows these basic steps: defining the problem, explaining it and trying to solve it, and controlling the problem. In this specific context of fatigued driving, these steps would mean establishing the raising of the fatigue-related effects while driving, identifying a way to solve them, and finally finding if they worked.

More specifically, this dissertation has two aims: one is to find what the best performance indicators are and to confirm the worsening of these parameters during the prolonged monotonous driving task; the other is to demonstrate the effectiveness of using caffeinated chewing gum against driving fatigue. In particular, I tried to show that caffeinated chewing gums have a faster effect than a cup of coffee on improving driving performance under prolonged and fatigued driving.

Even several studies have been conducted on the effectiveness of caffeine to reduce driving fatigue, this work is the first attempt to show that consuming caffeine chewing gum is the more effective and safest way to administer caffeine while driving, and so, it has more benefits than all the other treatments.

3.1 Methodology

In order to collect information about driving fatigue, a laboratory experiment was designed using a driving simulator.

3.1.1 Apparatus

Transport Research Laboratory's driving simulator at DICEA

There are two driving simulators at the Transport Research Laboratory of DICEA, Padua University. Specialized Dutch company ST Software B.V. builds them both. Jentig 50, is a static simulator, the other, Jentig 60, is dynamic. For this study Jentig 60 simulator had been used (in static mode).

To be clearer, software and hardware components will be separately described.

Eight modules make software package of the simulator. The system is very flexible and allows programmers to make ad-hoc-scenarios.

The eight modules can be divided in three groups:

Agent creation software:

- stRoadDesign: used to create road network;

- stScenario: used to create traffic agents and events during the simulation by scripts;

runtime simulation software:

- stControl: command panel, GUI;

- stSoundEngine: sound engine modulus;

- stTraffic: traffic calculation modulus;

- stRender: graphical 3D render;

saving and analysis software:

- stTraffic/stScenario: *data processing* and run-time modulus;

- stDataproc: off-line *data processing* modulus, based on GUI.

General operation of software components can be well represented by Figure 1. In the project phase, the first step is to create the graphical environment by using stRoadDesign: intersection, buildings, urban fabrics, background landscape can easily implemented. The next step is the creation of scenarios: here the programmer has to define traffic agents and traffic parameters by using stScenario. Run-time simulation is managed by stControl, stTraffic, and stRender and stSound modulus. These components allow the real-time reproduction of simulated environment. Finally, stDataProc defines data collection and analysis criteria.
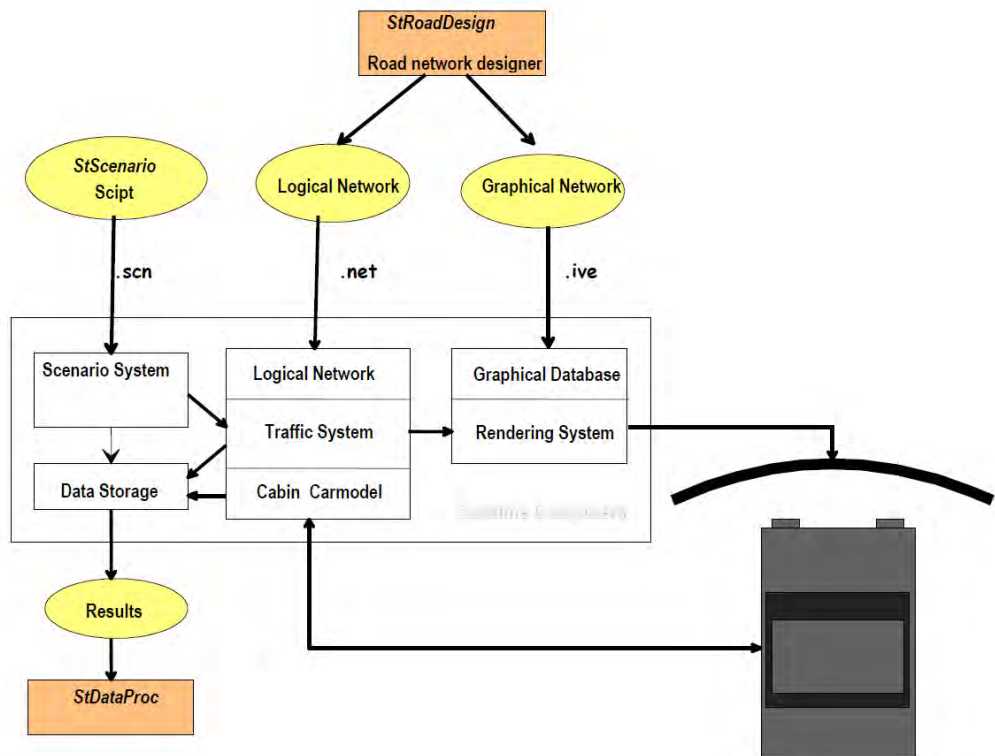
Figure 1: functional plan of the software modulus.

It is possible to monitor all the parameters during the simulation by GUI Figure 2.
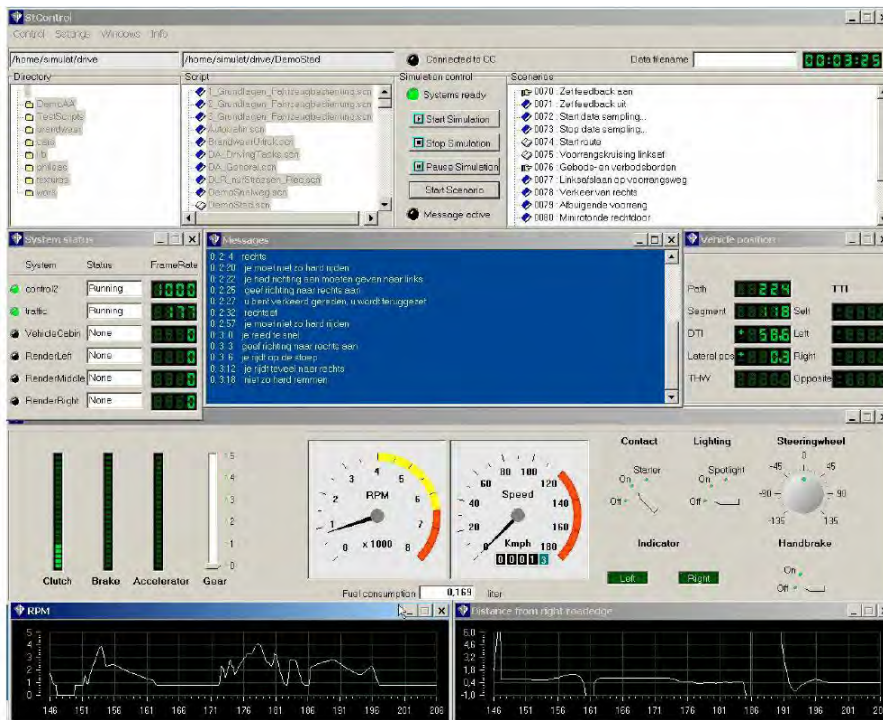
Figure 2: GUI interface.

Previously mentioned software modulus are installed in different PCs that are part of the driving simulator. In particular, developing scenario and designing virtual environment modulus software (stRoadDesign and stScenario) are installed in only one PC (*Control*). As we can deduce from Figure 3, *Control* PC does data processing and rendering of the central screen. Other two PCs make rendering for the other four screens (*Render 1* and *Render 2*).

Simulator software modules and PCs

PC's   Software modules

Control
- Operator interface
- Traffic simulation
- Scenario script processing
- Sound generation
- Kinect head tracking
- Graphical rendering Center screen

Render1
- CKAS motion platform driver
- Graphical rendering screens Left1, Right1

Render2
- Graphical rendering screens Left2, Right2
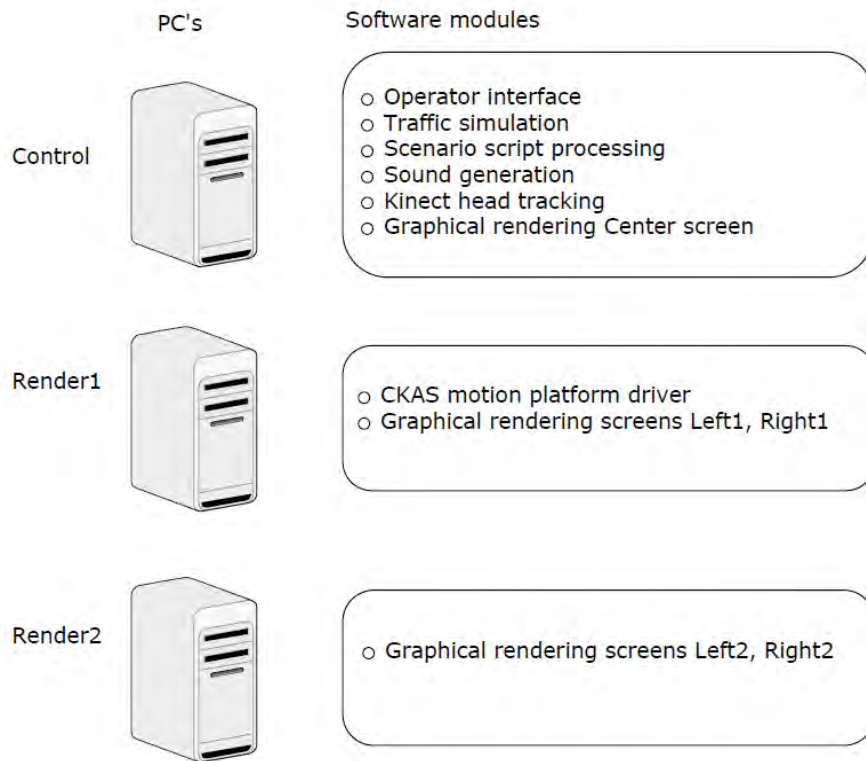
Figure 3: software modulus and PCs.

The following components complete the simulation system:

- the cockpit;

- Kinect camera;

- A dynamic platform as motion system.

Every component is linked to a LAN switch. PCs are always connected to the internet network and, through a Multicabin cable system, it is possible to link each other the driving simulators in the Laboratory (Figure 4).
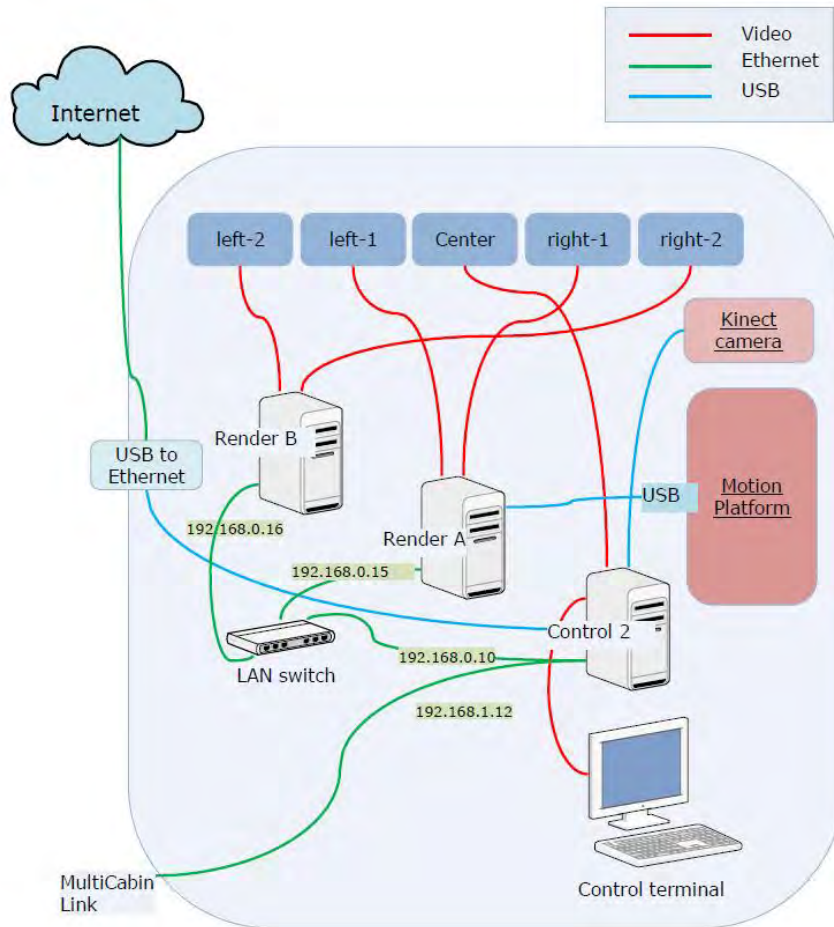
Figure 4: dynamic driving simulator network at Transport Research Laboratory of DICEA.

The PCs have an Intel Core i7-4770 @3.40 GHz, a couple of 4 GB DDR3 RAM, GeForce GTx260 as graphic card and Windows XP SP 3 as operative system.

Sound system is a 5.1 surround Logitech: three speakers (two frontal speakers and two rear speakers) and a subwoofer on the side of the pedalboard.

The "physical component" which the driver interact with is made by:

- aluminum and Plexiglas cockpit provided with a removable panel simulating the car's roof;

- steering wheel (18 cm radius) provided with force feedback, reproducing vibration and steering rigidity;

- pedalboard provided by brake, clutch and gas;

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- light, horn and turn signals levers;

- manual gearshift (can be set as automatic);

- manual brake;

- adjustable seat and seatbelt;

- five 60" LCD screens LG.

Driving simulator motion system is the CKAS 2DOF: a small and quite cheap two degrees of freedom platform (Figure 5). It can make the simulator rotating around longitudinal axes, upon the horizontal plane (X and Y).

Figure 5: CKAS 2DOF dynamic platform.

In this study dynamic platform was turned off and simulator was used in static mode.

Figure 6: driving simulator during an experiment.

StSoftware Jentig 60 driving simulator can collect a huge number of interesting measures. The choice of the parameters and the samples rate frequency is at discretion of the researcher.

For this investigation, the following parameters were particularly interesting:

- lateral position of the vehicle;

- gas pedal rate (named gas);

- lateral acceleration;

- speed of the vehicle.

3.1.2 Subjects

The drivers' sample used in the study was composed by 72 drivers (volunteers) not balanced concerning gender. They were students, staff of the University and other people having the following characteristics:

- at least 1 year of driving experience;

- at least 5,000 km of annual average driving distance;

- absence of sleep disorders (measured by Epworth Sleepiness Scale);

- they were told not to consume caffeine in the five hours before the experiment;

- they were told not to smoke in the five hours before the experiment.

	Mean	Standard Deviation	Range
Age	24.93	3.08	19 - 35
Coffee per day	1.87	1.53	0 - 5

Table 1: Test deriver's characteristics: age and coffee consumption.

3.1.3 Experiment design

A scenario of highway environment were built in virtual reality using the three-dimension rendering software by stSoftware. The scenario was based on a straight road 164 km long, with two driving lane (width 3.75 m) and a security lane (width 2.5 m). The right and left carriages were divided by a traffic island 1.80 m large as requested by the Italian law on road design (D.M. 05/11/2001).

The whole straight road was designed with a virtual banking (1.85 %) that managed to create a tendency to deviate to the right, requiring steer corrections by the driver to compensate it. Every 10 km a speed limit signal was positioned to remember the drivers the enforced 130 Km/h speed limit.

On the main direction, light traffic condition (flow rate around 300 vehicles/h/lane) was simulated. Because of drivers were told not to overtake, no slow vehicles were present on the right lane, but only a leader and a follower vehicles always moving at the same speed of the volunteer. Both vehicles travelled at a fixed distance of 50 m from the car. In order to enhance the naturalism of the scenario, on the other carriage (other direction) light traffic condition (flow rate around 350 vehicles/h/lane) was simulated. In this flow, the 10 % of vehicles were heavy vehicles.

In the laboratory room, the temperature was controlled between 20° C and 22° C, and the brightness measure by a light meter was fixed at 4 lx.

Participants were screened and familiarized with the simulator during a training day. In this session, subject performed a ten-minute swing drive and completed a Simulator Sickness Questionnaire [49] to identify possible simulator sickness. Moreover they filled the Epworth Sleepiness Scale test

[50] to identify excessive daytime sleepiness considered as sleep disorder. Selected subjects were randomly assigned to one of the analysed treatment.

Upon arrival, possible use of alcohol, caffeine or smoke of cigarette were checked by using a self reported questionnaire. When all criteria were met, the trial could be conducted.

The experiments were made following the same common structure. The volunteers were instructed to drive for 70 minutes in the center of the right lane as they normally do in the real world, at the speed of about 130 km/h. They also were told not to overtake leading vehicles and simply go straight following the street. The volunteers had to do two driving test in two different days: one with the administration (Cup of Coffee, Caffeinated Chewing Gum, or Placebo Gum) and another one as baseline-control test.

Summarizing the structure, the two trials of the experiment were divided in three or four parts, depending on the type of trial:

- Interview of the participant to collect information about his/her status of sleepiness and fatigue;

- 50 minutes of driving;

- Administration of the treatment;

- 20 minutes of driving;

- Interview of the participant to collect information about his/her status of sleepiness and fatigue and the driving task at the end of the trial and during the trial.

The experimental design adopted was specifically thought to consider the importance both of monotony and treatment.
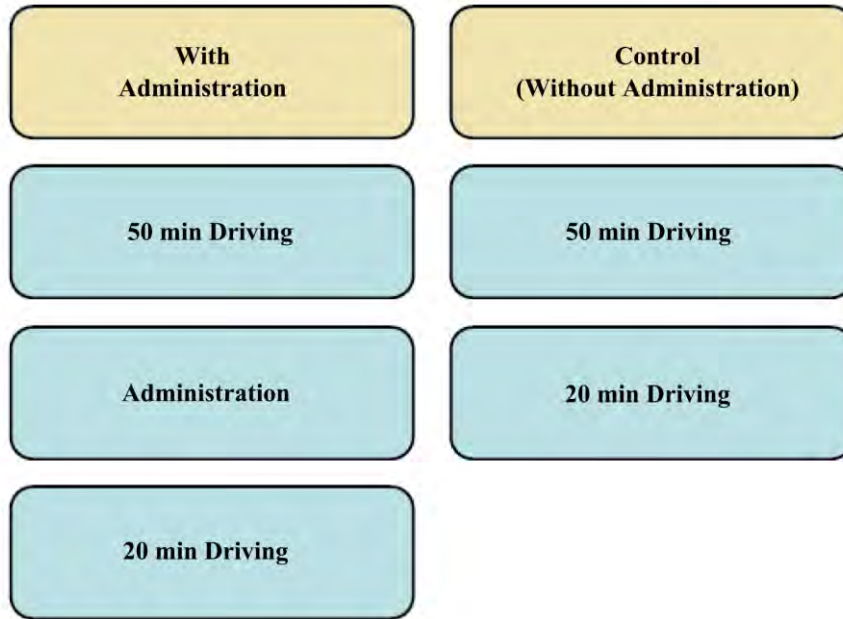
Figure 7: structure of the test days.

The scenario was the same for every type of administration and it had a monotonous environment: pairs of trees were regularly put on both sides of the road and facades of trees closed the line of vision at the horizon. Day time and good weather conditions were adopted in the scenario, a lite haze was put in the sky to make the background more realistic.

Aiming to consider the circadian effect as a block factor, test sessions were scheduled at the same time in the afternoon (15:30 − 19:00) for each trials. Indeed, as found in literature [51], this temporal window is out enough from the mid-afternoon dip (after lunch) and before the late-afternoon peak.

3.1.4 Response variables

Most common measures used in literature are mean and standard deviation of lateral position and mean and standard deviation of steering wheel movements. Sometimes it is possible to find the number of edge line crossings or standard deviation of speed.

The use of driving simulator allows to record various parameters describing the drivers behavior at high frequency (in this study , 10 Hz). For the first part of the study mean value and standard deviation of all

parameters were considered. After some trials, some measures were not considered because not significant as indicator of fatigue.

Because of the great number of data, to perform an ANOVA or a "linear mixed model analysis", it had been necessary to divide the whole driving session of 70 minutes in smaller intervals of 1 minute and 5 minute. For each interval, the mean and standard deviation of parameters were calculated.

The first 5 minutes interval was cut from the dataset because the driver had to adapt to the simulator. For a straight monotonous highway scenario, 5 minutes seemed enough to re adapt to the simulator driving feedback; as suggested in the literature [52], even if the driving simulator is not a high level simulator, participants can transfer their driving skills to the simulator after an appropriate adaptation period.

The 5 minutes immediately after the administration were also cut from the dataset because the state of driver had just been perturbed by the presence of the operator giving the administration to the volunteer. Therefore, elimination of data collected in these periods had been done in order to consider only data representing stable highway driving conditions.

Some data had been considered as "outliers" and they had been cut by the dataset using the following criteria:

- elimination of the data from the tests where an accident occurred;

- elimination of the data from the tests containing elevate value of standard deviation of lateral position for at least 1 interval of 5 minutes (std.dev.latera.pos > 0.70 m).

3.1.5 Subjective assessment

Before and after the driving session, questionnaires were administered on subjective sleepiness and fatigue following the widely used questionnaire presented in literature [36].

Subjective sleepiness was measured by using the Karolinska Sleepiness Scale (KSS), ranging from 1 (very alert) to 9 (very sleep, fighting sleep) [53]. Subjective sleepiness was measure by using a Visual Analog Scale (VAS), ranging from "not at all tired" to "extremely tired" [54]. All the questionnaire are presented in the Annex.

3.1.6 Data analysis

The analysis of the data was conducted using two different approaches:

- ANOVA or Kruskall-Wallis non parametric test;

- Linear mixed model or Generalized mixed models.

Every statistical technique previously mentioned has peculiarities from the others that permit to observe different aspects of the data. For all the way I analyzed the data, the aims were both to show a tendency of growth of the indicator of fatigue for about the first 50 minutes and to demonstrate different effects for different treatments in the last 20 minutes.

For the statistical analysis of the data *R-software* was used. A code was developed; an example of code structure is shown in Figure 8.
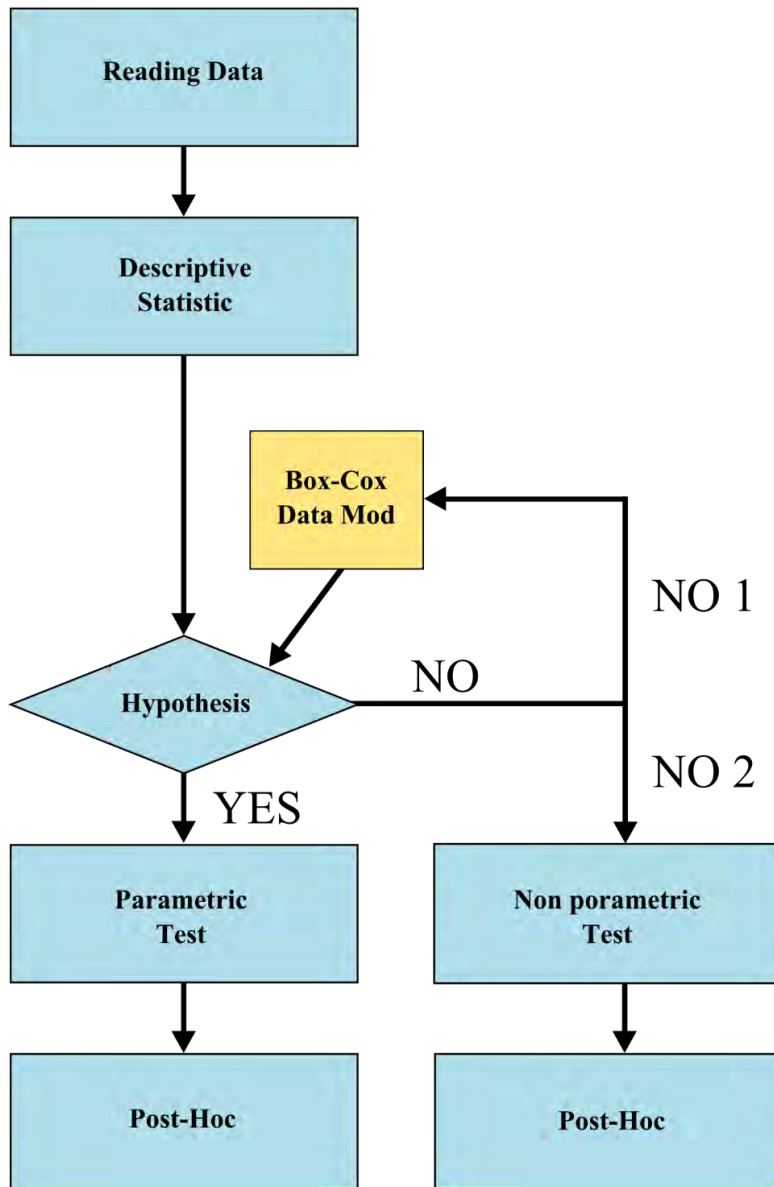
Figure 8: Analyses flow chart

3.1.6.1 ANOVA

Homoschedastic parametric ANOVA is the most widely used test for statistical analysis. It allows to compare more than two groups in a parametric way (every group must follow a Gaussian distribution of the data). Before going on with ANOVA test, it had been necessary to apply

a test for homoschedasticity: in this study, Flinger-Killeen test to every groups was used. If the hypotheses for ANOVA were not matched, I went on with a Box-Cox transformation of the data and rechecked the hypotheses.

The choice to use ANOVA was made considering:

- It is the most known and used inferential test;

- It is simple to use and simple to read;

- Easily linked to a linear model regression.

In order to understand the best dimension of the interval where to compute the most representative value of mean and standard deviation, ANOVA was applied to both intervals of 5 and 7.5 minutes. "TIME" and "TREATMENT" had been set as factors. If the parametric hypothesis was not matched, a Box-Cox transformation was applied to the data. Post-hoc analyses were then performed using the Tukey HSD test. Statistical significance of difference was set a *p-value< 0.05*.

With the same method, subjective sleepiness (KSS) and fatigue (VAS) were analyzed.

3.1.6.2 *Kruskal-Wallis non-parametric test*

When the homoschedasticity hypothesis matched, but the normality did not, Kruskal-Wallis non-parametric test was performed. It is a generalization of one-way ANOVA, so because the previous analyses were like a two-way ANOVA only particular cases were studied adopting Kruskal-Wallis test. The test does not identify where stochastic dominance occurs or for how many pairs of groups stochastic dominance obtains. Even Dunn's test is the most widely used post-hoc test for non-parametric hypothesis, it uses median values for comparisons. Thus, I decided to perform a Nemenyi test for multiple comparisons of rank sums of independent samples, which can obtain conclusion about differences of mean values.

A Generalized Linear Mixed Model analysis was also performed, but it will not be reported in this dissertation.

3.2 Results

3.2.1 Effect of driving task-related fatigue on performance

The aim of this chapter is to investigate on the best performance indicators to evaluate the driving fatigue onset and development during a prolonged monotonous driving task.

Since the aim of the chapter is to study the only effect of the fatigue on the performance, the dataset was composed only by the control trials: 61 trials 70-minute long of driving with no interruption.

Table 2 shows mean values and standard deviation of most relevant indicators of driving performance.

Time	Gas		Lateral Position		Steer	
[min]	Mean [cm]	St. Dev	Mean [cm]	St. Dev	Mean [°]	St. Dev
10	3,27	2,84	0,26	0,08	0,84	0,45
15	3,24	3,26	0,27	0,08	0,81	0,48
20	2,97	3,16	0,28	0,08	0,88	0,53
25	3,82	3,14	0,29	0,08	0,95	0,55
30	3,98	3,54	0,30	0,09	1,02	0,59
35	4,10	3,22	0,32	0,11	1,10	0,61
40	4,74	3,64	0,31	0,09	1,12	0,64
45	4,13	3,10	0,33	0,10	1,19	0,66
50	4,30	3,22	0,33	0,10	1,18	0,72
55	4,32	3,55	0,33	0,10	1,22	0,81
60	4,53	4,03	0,34	0,10	1,23	0,77
65	4,76	3,74	0,33	0,10	1,30	0,90
70	5,45	4,41	0,35	0,11	1,34	0,86

	Lateral Acceleration		Steer Error	
Time [min]	Mean [m/s^2]	St. Dev	Mean [°]	St. Dev
10	0,14	0,07	2,14	0,81
15	0,13	0,08	2,25	0,97
20	0,14	0,08	2,41	0,98
25	0,15	0,09	2,48	1,03
30	0,17	0,09	2,69	1,17
35	0,18	0,10	2,84	1,25
40	0,18	0,10	2,80	1,19
45	0,19	0,11	2,87	1,21
50	0,19	0,12	2,85	1,29
55	0,20	0,13	2,85	1,23
60	0,20	0,12	2,95	1,30
65	0,21	0,13	3,01	1,44
70	0,22	0,13	3,09	1,50

Table 2: effect of fatigue on different indicators of performance.

Because of the huge number of parameters have been analyzed, only the most relevant parameters have been reported here.

Standard deviation of Gas

Since the hypothesis of normality was rejected (p<2.2e^{-6}) and homogeneity of the variance confirmed (F(11,720)=1.2522, p=0.2484), a Kruskall-Wallis analysis was carried out. The analysis showed the significant main effects of Task Time (χ^2=31.11, p=0.0019). In particular, performing a post-hoc analysis using the pairwise comparison Tukey-Kramer (Nemenyi) test with 95% interval of confidence (α=0.05), significant difference between intervals has been found, Table 3.

	2	3	4	5	6	7	8	9	10	11	12	13
3	1.0000	–	–	–	–	–	–	–	–	–	–	–
4	0.9996	1.0000	–	–	–	–	–	–	–	–	–	–
5	0.9990	0.9755	0.8134	–	–	–	–	–	–	–	–	–
6	0.9992	0.9777	0.8221	1.0000	–	–	–	–	–	–	–	–
7	0.9741	0.8404	0.5202	1.0000	1.0000	–	–	–	–	–	–	–
8	0.5331	0.2554	0.0767	0.9861	0.9846	0.9997	–	–	–	–	–	–
9	0.9462	0.7594	0.4183	1.0000	1.0000	1.0000	0.9999	–	–	–	–	–
10	0.8262	0.5448	0.2320	0.9997	0.9996	1.0000	1.0000	1.0000	–	–	–	–
11	0.9509	0.7713	0.4317	1.0000	1.0000	1.0000	0.9999	1.0000	1.0000	–	–	–
12	0.9219	0.7042	0.3614	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	–	–
13	0.5298	0.2530	0.0757	0.9857	0.9842	0.9997	1.0000	0.9999	1.0000	0.9999	1.0000	–
14	0.0782	0.0207	0.0034	0.6009	0.5892	0.8690	0.9996	0.9240	0.9845	0.9177	0.9478	0.9997

Table 3: pairwise comparison between 5 minutes time intervals of std. dev. of Gas.

Figure 9 shows the mean values and the confidence interval of response variable *Std Dev Gas* during the experiment.

Figure 9: Std. Dev. of Gas: mean values and confidence interval in experimental condition.

<u>Standard deviation of Lateral Acceleration</u>

Since the hypothesis of normality ($p<2.2e^{-6}$) and homogeneity of the variance ($F_{(11,720)}=2.680$, $p=0.0022$) were rejected, a Box-Cox data transformation was performed and then a Kruskall-Wallis analysis was carried out. The analysis showed the significant main effects of Task Time ($\chi^2=46.11$, $p=6.694e^{-6}$). In particular, performing a post-hoc analysis using the pairwise comparison Tukey-Kramer (Nemenyi) test with 95% interval of confidence ($\alpha=0.05$), significant difference between intervals has been found, Table 4.

	2	3	4	5	6	7	8	9	10	11	12	13
3	1.0000	–	–	–	–	–	–	–	–	–	–	–
4	1.0000	0.9998	–	–	–	–	–	–	–	–	–	–
5	0.9983	0.9600	1.0000	–	–	–	–	–	–	–	–	–
6	0.8965	0.6288	0.9832	1.0000	–	–	–	–	–	–	–	–
7	0.3531	0.1283	0.6163	0.9563	0.9998	–	–	–	–	–	–	–
8	0.3444	0.1238	0.6065	0.9533	0.9998	1.0000	–	–	–	–	–	–
9	0.0756	0.0175	0.1976	0.6323	0.9610	1.0000	1.0000	–	–	–	–	–
10	0.2079	0.0626	0.4286	0.8712	0.9972	1.0000	1.0000	1.0000	–	–	–	–
11	0.1471	0.0401	0.3320	0.7961	0.9912	1.0000	1.0000	1.0000	1.0000	–	–	–
12	0.0989	0.0243	0.2444	0.6995	0.9768	1.0000	1.0000	1.0000	1.0000	1.0000	–	–
13	0.0571	0.0125	0.1574	0.5625	0.9383	0.9999	1.0000	1.0000	1.0000	1.0000	1.0000	–
14	0.0102	0.0017	0.0367	0.2290	0.6791	0.9906	0.9914	1.0000	0.9989	0.9998	1.0000	1.0000

Table 4: pairwise comparison between 5 minutes time intervals of std. dev. of Lateral Acceleration.

Figure 10 shows the mean values and the confidence interval of response variable Std. of lateral acceleration during the experiment.

Figure 10: Std. Dev. of Lateral Acceleration: mean values and confidence interval in experimental condition.

Standard deviation of Lateral Position

Since the hypothesis of normality was rejected ($p=1.947e^{-15}$) and homogeneity of the variance confirmed ($F_{(11,720)}=1.407$, $p=0.1669$), a Kruskall-Wallis analysis was carried out. The analysis showed the significant main effects of Task Time ($\chi^2=52.47$, $p=2.471e^{-7}$). In particular, performing a post-hoc analysis using the pairwise comparison Tukey-

Kramer (Nemenyi) test with 95% interval of confidence (α=0.05), significant difference between intervals has been found, Table 5.

	2	3	4	5	6	7	8	9	10	11	12	13
3	0.99925	–	–	–	–	–	–	–	–	–	–	–
4	0.90066	0.99995	–	–	–	–	–	–	–	–	–	–
5	0.89265	0.99993	1.00000	–	–	–	–	–	–	–	–	–
6	0.20662	0.83027	0.99682	0.99733	–	–	–	–	–	–	–	–
7	0.05490	0.49387	0.93152	0.93742	1.00000	–	–	–	–	–	–	–
8	0.15507	0.76015	0.99185	0.99297	1.00000	1.00000	–	–	–	–	–	–
9	0.01099	0.19976	0.68551	0.69954	0.99913	1.00000	0.99977	–	–	–	–	–
10	0.00429	0.10815	0.50699	0.52192	0.99266	0.99996	0.99719	1.00000	–	–	–	–
11	0.00379	0.09950	0.48458	0.49940	0.99085	0.99994	0.99636	1.00000	1.00000	–	–	–
12	0.00034	0.01723	0.15987	0.16799	0.85338	0.98611	0.90533	0.99982	1.00000	1.00000	–	–
13	0.00148	0.04159	0.32997	0.34283	0.96385	0.99908	0.98174	1.00000	1.00000	1.00000	1.00000	–
14	4.7e-05	0.00377	0.04255	0.04690	0.59652	0.89505	0.68329	0.99167	0.99896	0.99924	1.00000	0.99995

Table 5: pairwise comparison between 5 minutes time intervals of std. dev. of Lateral Position.

Figure 11 shows the mean values and the confidence interval of response variable Std. Dev. Of lateral position during the experiment.

Figure 11: Std. Dev. of Lateral Position: mean values and confidence interval in experimental condition.

<u>Standard deviation of Steer</u>

Since the hypothesis of normality ($p<2.2e^{-6}$) and homogeneity of the variance ($F(11,720)=2.671$, $p=0.0023$) were rejected, a Box-Cox data transformation was performed and then a Kruskall-Wallis analysis was carried out. The analysis showed the significant main effects of Task Time ($\chi^2=42.12$, $p=1.425e^{-5}$). In particular, performing a post-hoc analysis using the pairwise comparison Tukey-Kramer (Nemenyi) test with 95% interval of confidence ($\alpha=0.05$), significant difference between intervals has been found, Table 6.

	2	3	4	5	6	7	8	9	10	11	12	13
3	1.0000	–	–	–	–	–	–	–	–	–	–	–
4	1.0000	0.9999	–	–	–	–	–	–	–	–	–	–
5	0.9991	0.9670	1.0000	–	–	–	–	–	–	–	–	–
6	0.9124	0.6446	0.9826	1.0000	–	–	–	–	–	–	–	–
7	0.3963	0.1436	0.6282	0.9580	0.9999	–	–	–	–	–	–	–
8	0.4142	0.1532	0.6469	0.9632	0.9999	1.0000	–	–	–	–	–	–
9	0.1032	0.0240	0.2276	0.6707	0.9730	1.0000	1.0000	–	–	–	–	–
10	0.2494	0.0750	0.4527	0.8822	0.9980	1.0000	1.0000	1.0000	–	–	–	–
11	0.2009	0.0562	0.3847	0.8359	0.9954	1.0000	1.0000	1.0000	1.0000	–	–	–
12	0.1258	0.0307	0.2668	0.7217	0.9825	1.0000	1.0000	1.0000	1.0000	1.0000	–	–
13	0.0753	0.0162	0.1756	0.5892	0.9514	1.0000	0.9999	1.0000	1.0000	1.0000	1.0000	–
14	0.0135	0.0021	0.0402	0.2387	0.7025	0.9913	0.9896	1.0000	0.9988	0.9996	1.0000	1.0000

Table 6: pairwise comparison between 5 minutes time intervals of std. dev. of Steer.

Figure 12 shows the mean values and the confidence interval of response variable during the experiment.
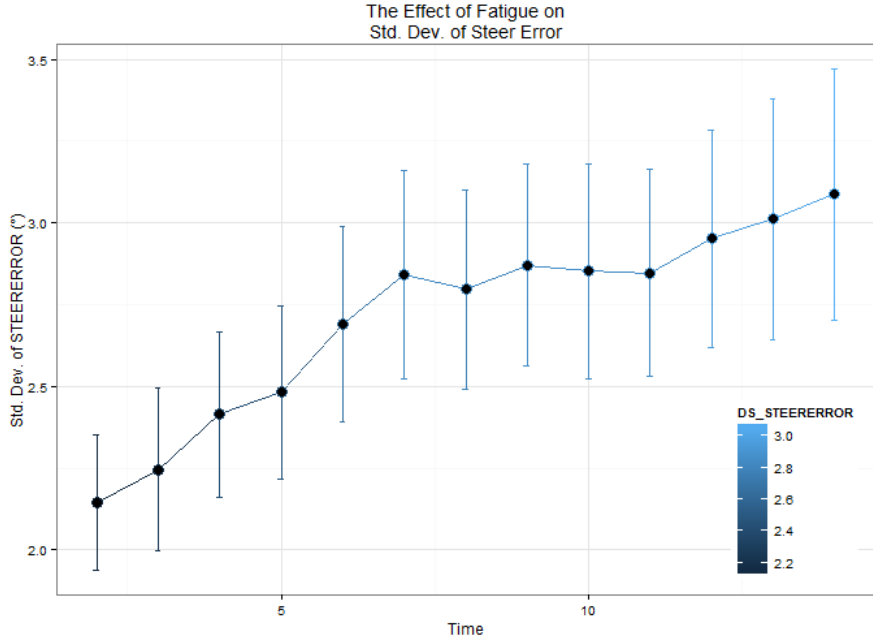
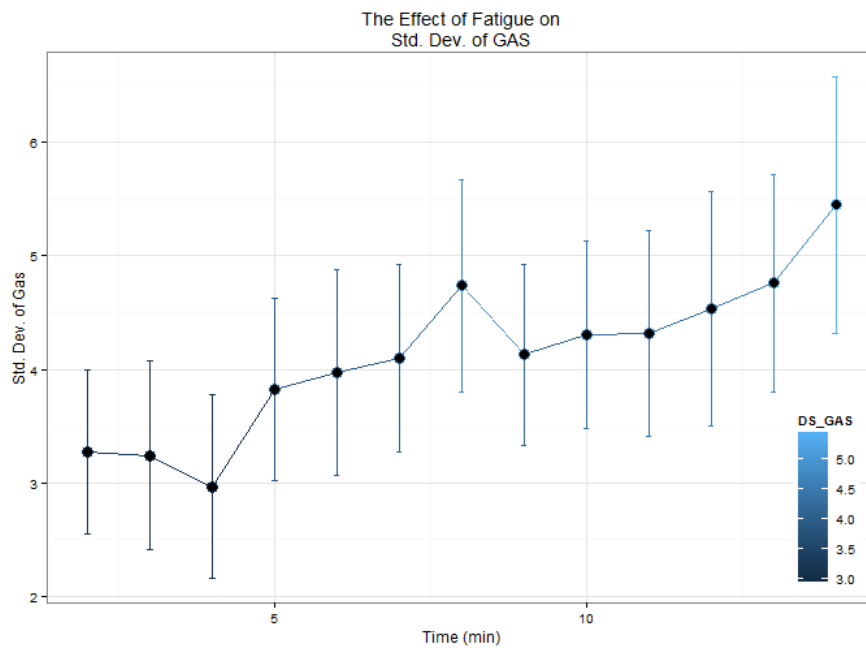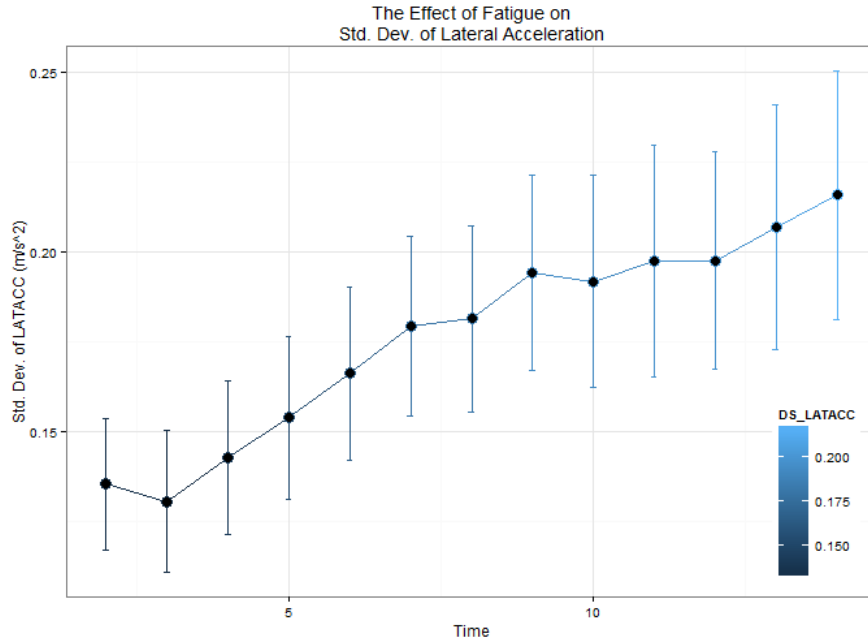*Figure 12: Std. Dev. of Steer: mean values and confidence interval in experimental condition.*

Standard deviation of Steer Error

Since the hypothesis of normality was rejected ($p<2.2e^{-16}$) and homogeneity of the variance confirmed ($F_{(11,720)}=1.172$, $p=0.0566$), a Kruskall-Wallis analysis was carried out. The analysis showed the significant main effects of Task Time ($\chi^2=44.12$, $p=1.444e^{-5}$). In particular, performing a post-hoc analysis using the pairwise comparison Tukey-Kramer (Nemenyi) test with 95% interval of confidence ($\alpha=0.05$), significant difference between intervals has been found, Table 7.

	2	3	4	5	6	7	8	9	10	11	12	13
3	1.0000	–	–	–	–	–	–	–	–	–	–	–
4	0.9807	0.9987	–	–	–	–	–	–	–	–	–	–
5	0.8990	0.9823	1.0000	–	–	–	–	–	–	–	–	–
6	0.3347	0.5845	0.9928	0.9997	–	–	–	–	–	–	–	–
7	0.0565	0.1505	0.7844	0.9356	1.0000	–	–	–	–	–	–	–
8	0.0769	0.1936	0.8423	0.9609	1.0000	1.0000	–	–	–	–	–	–
9	0.0253	0.0767	0.6146	0.8340	0.9992	1.0000	1.0000	–	–	–	–	–
10	0.0571	0.1517	0.7863	0.9365	1.0000	1.0000	1.0000	1.0000	–	–	–	–
11	0.0411	0.1157	0.7193	0.9014	0.9998	1.0000	1.0000	1.0000	1.0000	–	–	–
12	0.0112	0.0379	0.4453	0.6916	0.9936	1.0000	1.0000	1.0000	1.0000	1.0000	–	–
13	0.0092	0.0321	0.4092	0.6555	0.9907	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	–
14	0.0022	0.0089	0.1977	0.3931	0.9297	0.9996	0.9989	1.0000	0.9996	0.9999	1.0000	1.0000

Table 7: pairwise comparison between 5 minutes time intervals of std. dev. of Steer Error.

Figure 13 shows the mean values and the confidence interval of response variable Std. Dev. of steer error during the experiment.

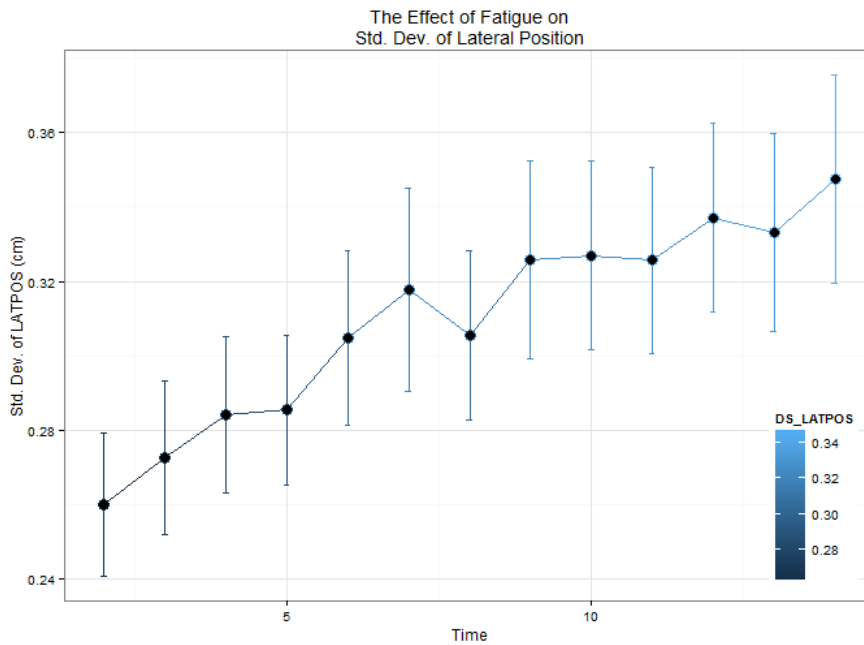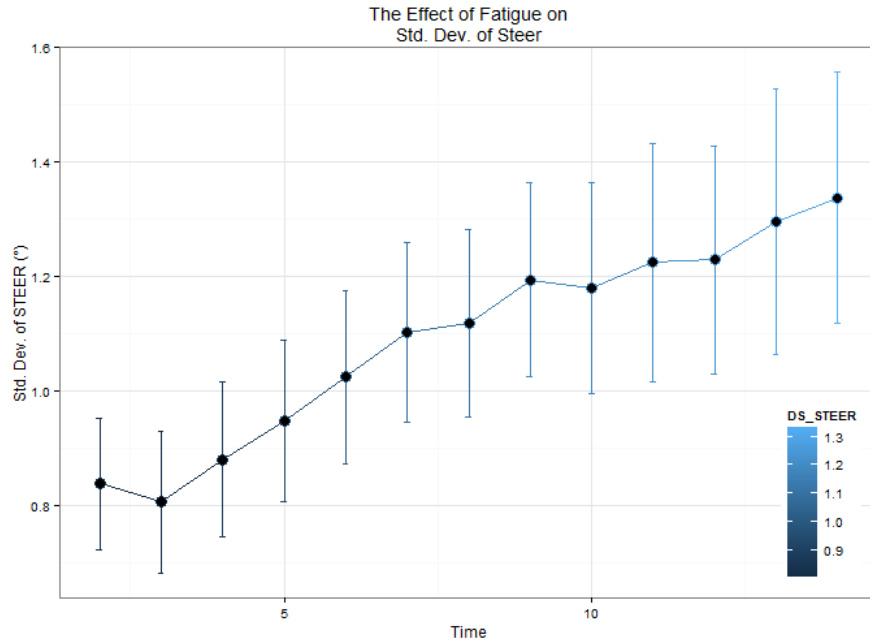*Figure 13: Std. Dev. of Steer Error: mean values and confidence interval in experimental condition.*

3.2.1.1 Discussion

All the parameters presented in the previous chapter showed a significant effect of time of task. Other variables had been analyzed but they did not seem to be affected by the effect of fatigue on time. Mean and standard deviation of every parameters, computed on five minutes interval, were considered: no mean value has given a significant response to fatigue development, probably because of the great variability of the data, due to the variability between the subjects. Only standard deviation of gas, lateral acceleration, lateral position, steer, steer error, and steer speed resulted as significantly affected by the time of driving task.

According to previous studies, as the duration of a driving task increases, driving performance decreases [2]. A peak of driving impairment occurs after about 30 minutes [2] and a plateau in performance about 50 minutes [47]. These findings suggest that the proposed simulator design can reproduce the onset of the driver fatigue phenomenon and how it manifests itself.

According to literature [55], standard deviation of lateral position is the best indicator of performance and can best represent the driving impairment caused by fatigue. In addition, standard deviation of steer error can be consider a quite good indicator.

3.2.2 Effect of caffeinated chewing gum on driving performance during prolonged simulated driving task

This study aimed to demonstrate the positive effect of caffeinated gum on driving performance during prolonged simulated highway driving task. To perform this analysis, the whole dataset was divided in three subset of 24 subjects, in order to make it possible to set three different "within" analyses to study separately the effect of Caffeinated Chewing Gum, Cup of Coffee, and Placebo Gum versus their related control trials.

Following the main results of the preliminary experiment (see 3.2.1), and previous findings in literature [6, 37, 56, 18, 19, 55], Standard Deviation of Lateral Position and Standard Deviation of Steer Error had been chosen as representative of driving behaviors.

3.2.2.1 Caffeinated gum vs. Control

The characteristics of the group of subject administered with Caffeinated Gum are summarized in Table 8.

	Mean	Std. Dev.	Range
Age	24.13	2.33	19 - 29
Coffee per day	1.75	1.48	0 - 4

Table 8: Test deriver's characteristics: age and coffee. Caffeinated Gum group.

<u>Subjective Sleepiness Evaluation (KSS)</u>

A two-way ANOVA with Task Time (3 levels: before driving test, after 50 minutes, and after 70 minutes) and Administration (Caffeinated Gum and Control) as within-subject factors was performed on Karolinska Sleepiness Scale index. Table 9 and Figure 14 show the variations observed in drivers' KSS scores.

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Time	Control		Caff. Gum	
	Mean	Std. Dev.	Mean	Std. Dev.
1	3,50	1,70	3,47	1,31
2	4,75	1,83	5,37	1,83
3	5,00	2,03	3,89	1,49

Table 9: mean and Std. Dev. of drivers' KSS: before, during and after the guide. (Caff. Gum)

We did find the effect of Caffeinated Gum during the tests with administration. Indeed, since there is a growth in perception of sleepiness between before the test and after 50-minutes of driving (interval 1-2: $p=0.061$), the score of KSS seems to return to the initial condition at the end of the driving session (intervals 1-3: $p=0.684$; intervals 2-3: $p=0.014$). On the contrary, during the Control trials, the score of KSS increased during the first part of the trial (intervals 1-3: $p=0.035$) and persisted on the same level during the last part of the driving session (intervals 2-3: $p=0.905$).
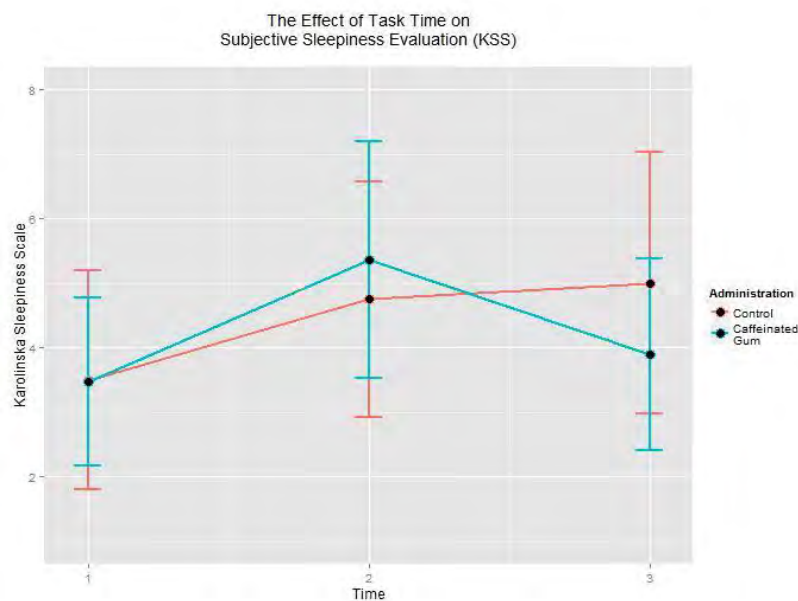
Figure 14: Karonlinska Sleepiness Scale score. (Caff. Gum)

Subjective Fatigue Evaluation (VAS)

A two-way ANOVA with Task Time (3 levels: before driving test, after 50 minutes, and after 70 minutes) and Administration (Caffeinated Gum and Control) as within-subject factors was performed on Visual Analog

Scale index. Table 10 and Figure 15 show the variations observed in drivers' VAS scores.

Time	Control		Caff. Gum	
	Media	Std. Dev.	Media	Std. Dev.
1	2,83	1,90	3,43	2,13
2	4,92	2,13	5,74	2,21
3	5,49	2,17	4,35	2,17

Table 10: mean and Std. Dev. of drivers' VAS: before, during and after the guide. (Caff. Gum)

We did find the effect of Caffeinated Gum during the tests with administration. Indeed, since there is a growth in perception of fatigue between before the test and after 50-minutes of driving (interval 1-2: p=0.005), the score of VAS seems to return to the initial condition at the end of the driving session (intervals 1-3: p=0.397). During the Control trials, the score of VAS increased during the first part of the trial (intervals 1-3: p<0.001) and persisted on the same level during the last part of the driving session (intervals 2-3: p=0.660). It confirms what found in literature: there is a plateau in self-perceived level of fatigue after about 50 minutes of driving [47].
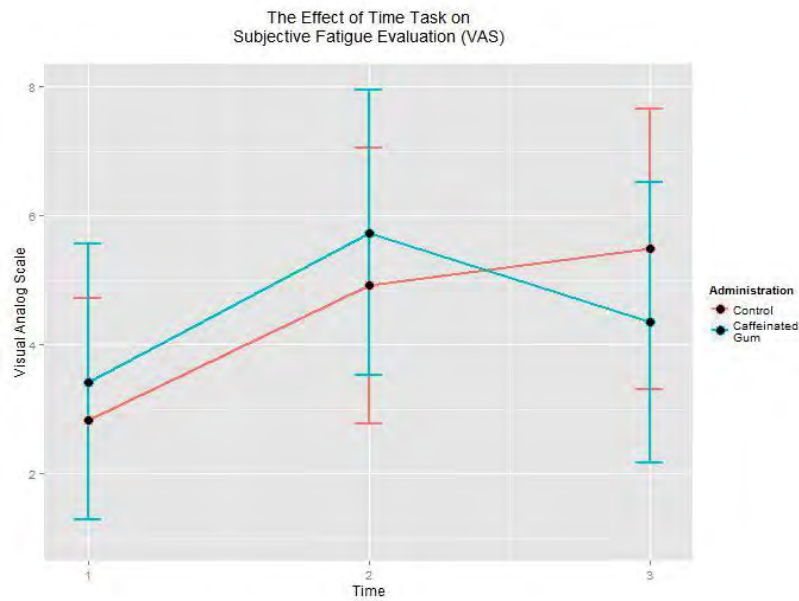
Figure 15: Visual Analog Scale index for self-perceived fatigue. (Caff. Gum)

Standard Deviation of Lateral Position

A two-way ANOVA with Task Time (8 levels plus 3 levels) and Administration (Caffeinated Gum and Control) as within-subject factors was performed on variable Standard Deviation of Lateral Position. After the data-cleaning process (see 3.1.4), one trial from Control group and two trials from Caffeinated Gum had been discarded: in two trials an incidents occurred and one trial presented outlier values.

Table 11 lists the summary statistics (means and standard deviations) according to the control and administration.

	Control		Caff. Gum	
Time.int	Mean [m]	Std.Dev [m]	Mean [m]	Std.Dev [m]
2	0,275	0,102	0,256	0,058
3	0,283	0,101	0,280	0,074
4	0,301	0,104	0,265	0,060
5	0,311	0,105	0,310	0,081
6	0,331	0,138	0,305	0,088
7	0,318	0,117	0,309	0,093
8	0,318	0,099	0,316	0,095
9	0,337	0,115	0,328	0,096
10	0,344	0,125	0,352	0,126
12	0,343	0,121	0,274	0,080
13	0,347	0,127	0,283	0,075
14	0,369	0,137	0,288	0,087

Table 11: Std. Dev. of Lateral Position. Summary statistics. (Caff. Gum)

Since ANOVA hypothesis were rejected, a Box-Cox data transformation had been implemented. First interesting fact was to check if there was any differences before the administration: as we expected, the analysis showed that in the first 50 minutes of driving there was no significant differences between the Caffeinated Gum and the control $(F(1,395)=0.1165,$ $p=0.733)$, but there was a significant main effect of Task Time $(F(8,935)=2.992, p=0.003)$.

After that, to check the efficacy of the Caffeinated Gum, an ANOVA for the "second" part of the trials was carried out. The analysis showed the significant main effect of the Caffeinated Gum $(F(1,175)=8.580, p=0.004)$.
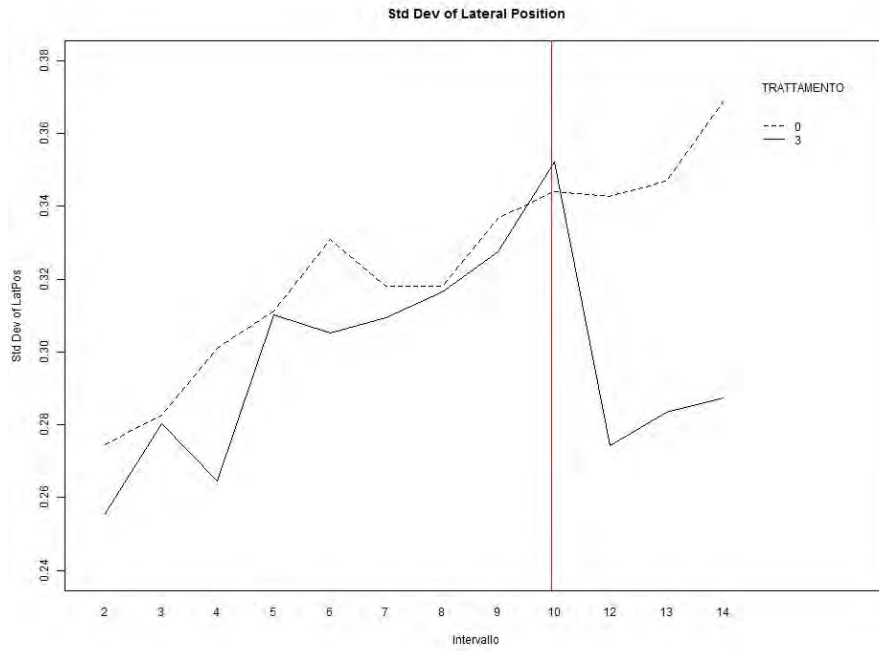
Figure 16: Std. Dev. of Lateral position: Caffeinated Gum (3) vs Control (0).
Red line: moment of the administration.

Finally, residual diagnostics were produced to verify if the model fitted properly with the dataset. The adoption of the reduced model produced an improvement in the quantile-quantile plot of residuals even if the values of parameters did not vary in a relevant manner from the original model. It implies that the original model had a good capability in representing the dataset.
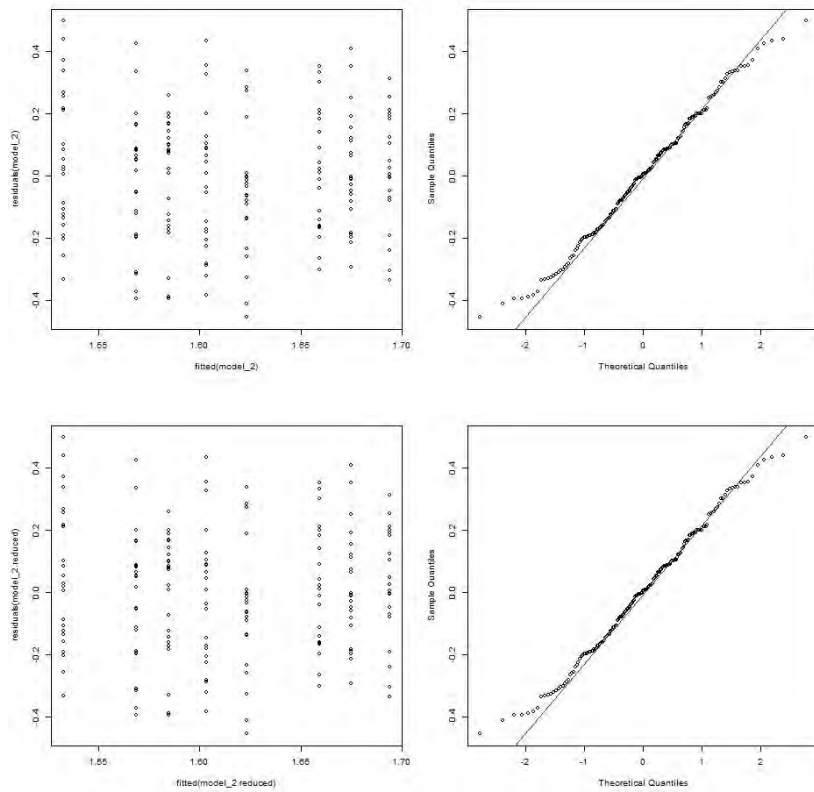
Figure 17: Residual diagnostics for the models before (upper diagrams) and after (lower diagrams) removal of data points with residual at distance greater than 2.5 standard deviations from zero. (Caff. Gum)

Standard Deviation of Steer Error

A two-way ANOVA with Task Time (8 levels plus 3 levels) and Administration (Caffeinated Gum and Control) as within-subject factors was performed on variable Standard Deviation of Steer Error. After the data-cleaning process (see 3.1.4), one trial from Control group and two trials from Caffeinated Gum had been discarded: in two trials an incidents occurred and one trial presented outlier values.

Table 12 lists the summary statistics (means and standard deviations) according to the administration.

Since ANOVA hypothesis were rejected a Box-Cox data transformation had been implemented. As previously done, first interesting fact was to check if there was any differences before the administration. As we expected, the analysis showed that in the first part of the trial, before the administration, there was no significant differences between caffeinated

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chewing gum and control (F(1,413)=0.271, p=0.603), but there was a significant main effect of Task Time (F(8,413)=2.529, p=0.011).

Time.int	Control		Caff. Gum	
	Mean [°]	Std. Dev. [°]	Mean [°]	Std. Dev. [°]
2	2,25	0,98	2,23	0,85
3	2,35	1,13	2,44	1,01
4	2,69	1,24	2,31	0,84
5	2,78	1,28	2,69	1,14
6	3,05	1,54	2,76	1,06
7	2,83	1,40	2,84	1,12
8	2,92	1,44	2,98	1,33
9	3,01	1,39	3,10	1,46
10	3,04	1,70	3,19	1,54
12	3,20	1,68	2,37	0,91
13	3,21	1,84	2,44	0,86
14	3,45	1,98	2,48	0,99

Table 12: Std. Dev. of Steer Error. Summary statistics. (Caff. Gum)

After that, to check the efficacy of Caffeinated Gum, an ANOVA for the "second" part of the trials was carried out. The analysis showed the significant main effect of Caffeinated Gum(F(1,183)=4.616, p=0.033).
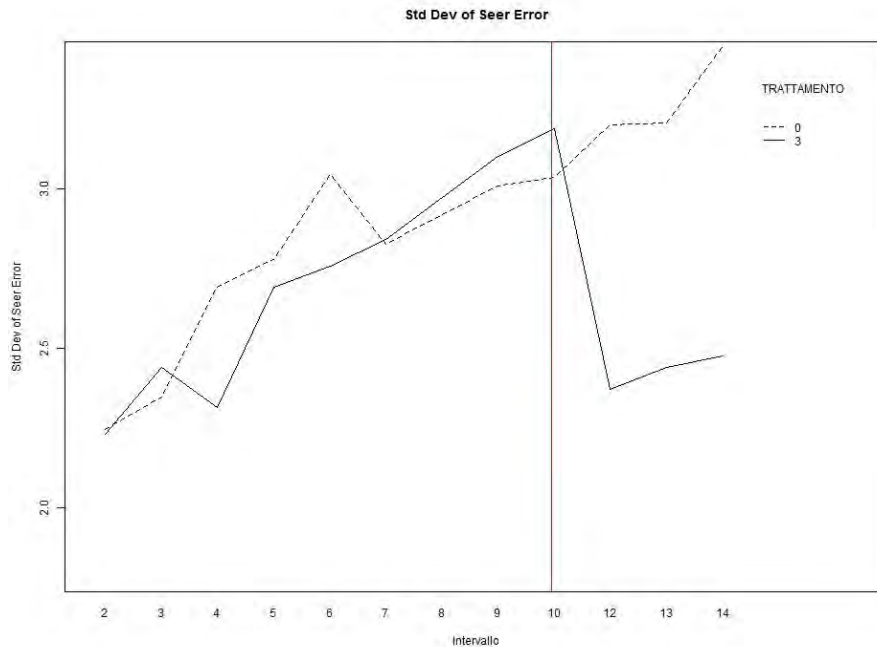
Figure 18: Std. Dev. of Steer Error: Caffeinated Gum (3) vs Control (0).
Red line: moment of the administration.

Again, residual diagnostics were produced to verify if the model fitted properly with the dataset. The adoption of the reduced model produced an improvement in the quantile-quantile plot of residuals even if the values of parameters did not vary in a relevant manner from the original model. It implies that the original model had a good capability in representing the dataset.

Figure 19: Residual diagnostics for the models before (upper diagrams) and after (lower diagrams) removal of data points with residual at distance greater than 2.5 standard deviations from zero. (Caff. Gum)

3.2.2.2 Cup of Coffee vs. Control

The characteristics of the group of subject administered with Cup of Coffee are resumed at Table 13.

	Mean	Std. Dev.	Range
Age	23.96	3.38	20 - 35
Coffee per day	1.75	1.54	0 - 5

Table 13: Test deriver's characteristics: age and coffee. Cup of Coffee group.

Subjective Sleepiness Evaluation (KSS)

A two-way ANOVA with Task Time (3 levels: before driving test, after 50 minutes, and after 70 minutes) and Administration (Cup of Coffee and Control) as within-subject factors was performed on Karolinska Sleepiness Scale index. Table 14 and Figure 20 show the variations observed in drivers' KSS scores.

Time	Control		Caff. Gum	
	Media	Std. Dev.	Media	Std. Dev.
1	3,57	1,75	3,55	1,50
2	6,24	1,76	5,30	2,15
3	6,24	1,76	4,60	2,14

Table 14: mean and Std. Dev. of drivers' KSS: before, during and after the guide. (Cup of Coffee)

We found the effect of Cup of Coffee during the tests with administration. Indeed, since there is a growth in perception of sleepiness between before the test and after 50-minutes of driving (interval 1-2: $p=0.017$), the score of KSS seems to return to the initial condition at the end of the driving session (intervals 1-3: $p=0.215$; intervals 2-3: $p=0.498$). As for the control of "Caffeinated Gum" group, during the Control trials, the score of KSS increased during the first part of the trial (intervals 1-2: $p<0.001$) and persisted on the same level during the last part of the driving session (intervals 2-3: $p=1.000$).
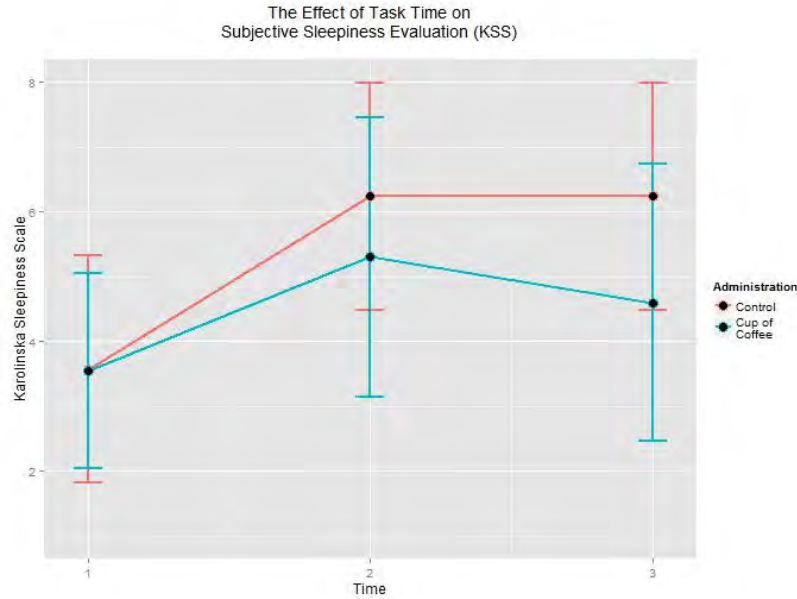
Figure 20: Karonlinska Sleepiness Scale score. (Cup of Coffee)

Subjective Fatigue Evaluation (VAS)

A two-way ANOVA with Task Time (3 levels: before driving test, after 50 minutes, and after 70 minutes) and Administration (Cup of Coffee and Control) as within-subject factors was performed on Visual Analog Scale index. Table 15 and Figure 21 show the variations observed in drivers' VAS scores.

Time	Control		Caff. Gum	
	Media	Std. Dev.	Media	Std. Dev.
1	2,83	1,90	3,43	2,13
2	4,92	2,13	5,74	2,21
3	5,49	2,17	4,35	2,17

Table 15: mean and Std. Dev. of drivers' VAS: before, during and after the guide. (Cup of Coffee)

We did not find the effect of Cup of Coffee during the tests with administration. Indeed, since there is a growth in perception of fatigue between before the test and after 50-minutes of driving (interval 1-2: p<0.001), the score of VAS does not seem to return to the initial condition at the end of the driving session (intervals 1-3: p=0.002; intervals: 2-3: p=0.958). The same happened during the Control trials, the score of VAS

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increased during all the duration of the trial (Intervals 1-3: p<0.001; intervals 1-2: p<0.001; intervals 2-3: p=0839).
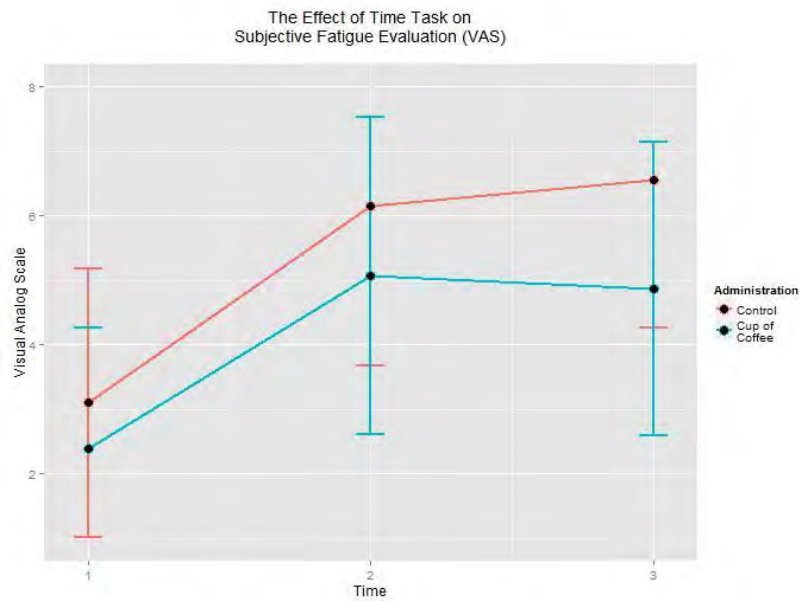
Figure 21: Visual Analog Scale index for self-perceived fatigue. (Cup of Coffee)

Standard Deviation of Lateral Position

A two-way ANOVA with Task Time (8 levels plus 3 levels) and Administration (Cup of Coffee and Control) as within-subject factors was performed on variable Standard Deviation of Lateral Position. After the data-cleaning process, two trial from Control group and one trials from Cup of Coffee had been discarded: in three trials an incidents occurred.

Table 16 lists the summary statistics (means and standard deviations) according to the administration.

Time.int	Control		Cup of Coffee	
	Mean [m]	Std. Dev. [m]	Mean [m]	Std. Dev. [m]
2	0,254	0,067	0,242	0,066
3	0,287	0,111	0,265	0,106
4	0,293	0,115	0,287	0,160
5	0,288	0,104	0,289	0,126
6	0,302	0,094	0,316	0,152
7	0,317	0,122	0,313	0,120
8	0,303	0,103	0,333	0,129
9	0,318	0,108	0,323	0,093
10	0,317	0,115	0,325	0,101
12	0,338	0,113	0,300	0,095
13	0,349	0,161	0,315	0,110
14	0,367	0,133	0,303	0,074

Table 16: Std. Dev. of Lateral Position. Summary statistics. (Cup of Coffee)

Since ANOVA hypothesis were rejected a Box-Cox data transformation had been implemented. First interesting fact was to check if there was any differences before the administration: as we expected, the analysis showed that in the first 50 minutes of driving there was no significant differences between Cup of Coffee and the Control($F_{(1,395)}=0.038$, p=0.845), but there was a significant main effect of Task Time ($F_{(8,395)}=3.317$, p=0.001).

After that, to check the efficacy of the Cup of Coffee, an ANOVA for the "second" part of the trials was carried out. The analysis showed there was not a significant main effect of Cup of Coffee ($F_{(1,175)}=2.826$, p=0.095).
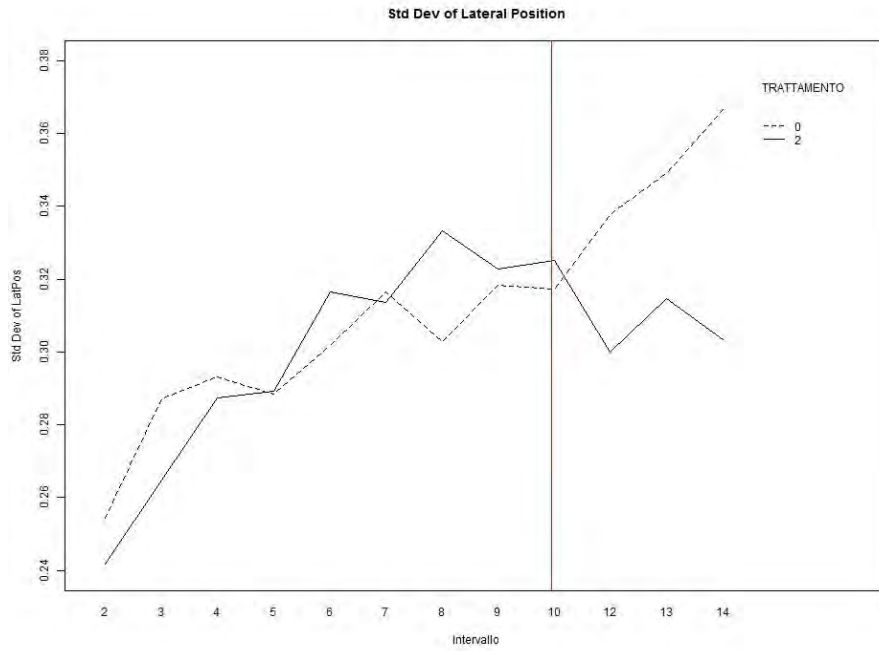
Figure 22: Std. Dev. of Lateral position: Cup of Coffee (2) vs Control (0).
Red line: moment of the administration.

Finally, residual diagnostics were produced to verify if the model fitted properly with the dataset. The adoption of the reduced model produced an improvement in the quantile-quantile plot of residuals even if the values of parameters did not vary in a relevant manner from the original model. It implies that the original model had a good capability in representing the dataset.
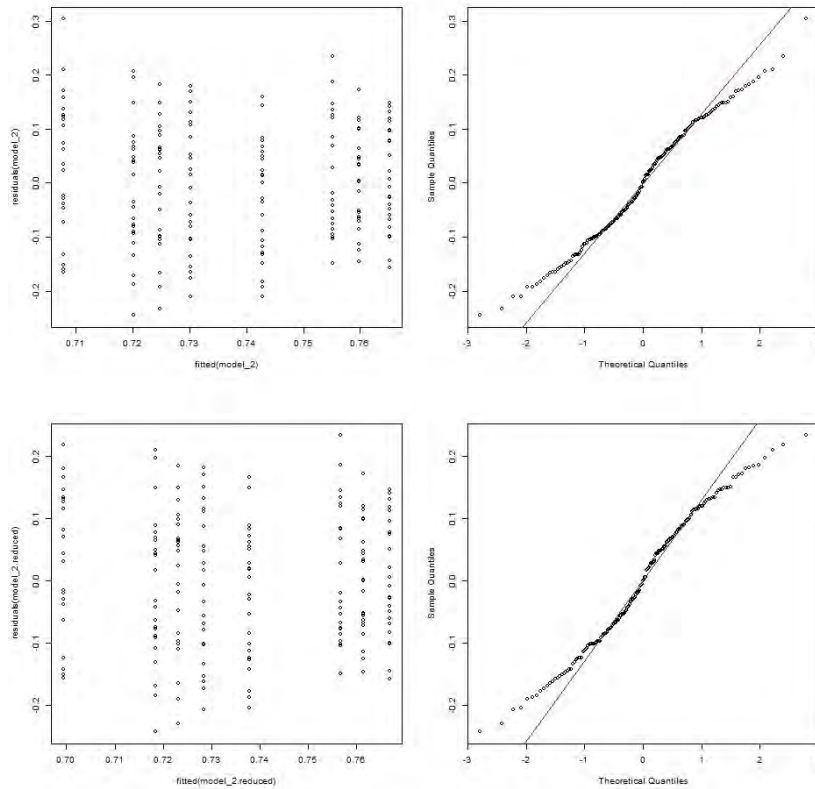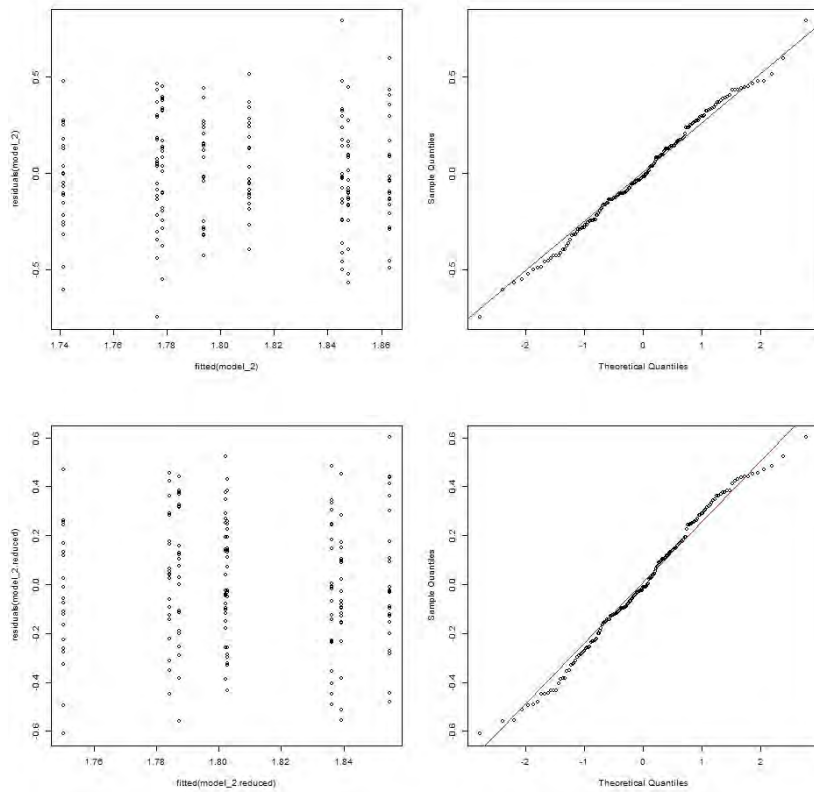
Figure 23: Residual diagnostics for the models before (upper diagrams) and after (lower diagrams) removal of data points with residual at distance greater than 2.5 standard deviations from zero. (Cup of Coffee)

<u>Standard Deviation of Steer Error</u>

A two-way ANOVA with Task Time (8 levels plus 3 levels) and Administration (Caffeinated Gum and Control) as within-subject factors was performed on variable Standard Deviation of Steer Error. After the data-cleaning process (see 3.1.4), two trial from Control group and one trials from Caffeinated Gum had been discarded: in three trials an incidents occurred.

Table 17 lists the summary statistics (means and standard deviations) according to the control and administration.

Since ANOVA hypothesis were rejected a Box-Cox data transformation had been implemented. As previously done, first interesting fact was to check if there was any differences before the administration. As we expected, the analysis showed that in the first50 minutes of driving, there was no significant differences between Cup of Coffee and Control

(F(1,935)=0.193, p=0.661), but there was a significant main effect of Task Time (F(8,395)=3.069, p=0.002).

Time.int	Control		Cup of Coffee	
	Mean [°]	Std. Dev. [°]	Mean [°]	Std. Dev. [°]
2	2,03	0,70	1,88	0,66
3	2,35	1,19	2,09	0,87
4	2,52	1,33	2,23	1,31
5	2,42	1,34	2,45	1,31
6	2,46	1,06	2,50	1,24
7	2,79	1,45	2,47	0,91
8	2,56	1,12	2,80	1,21
9	2,71	1,26	2,63	0,94
10	2,64	1,17	2,75	1,24
12	2,78	1,20	2,35	0,77
13	2,98	1,50	2,43	0,78
14	3,00	1,45	2,32	0,74

Table 17: Std. Dev. of Steer Error. Summary statistics. (Cup of Coffee)

After that, to check the efficacy of the Cup of Coffee, an ANOVA for the "second" part of the trials was carried out. On the contrary we expected, the analysis showed significant main effect of Cup of Coffee for the Standard Deviation of Steer Error (F(1,175)=4.075, p=0.045).
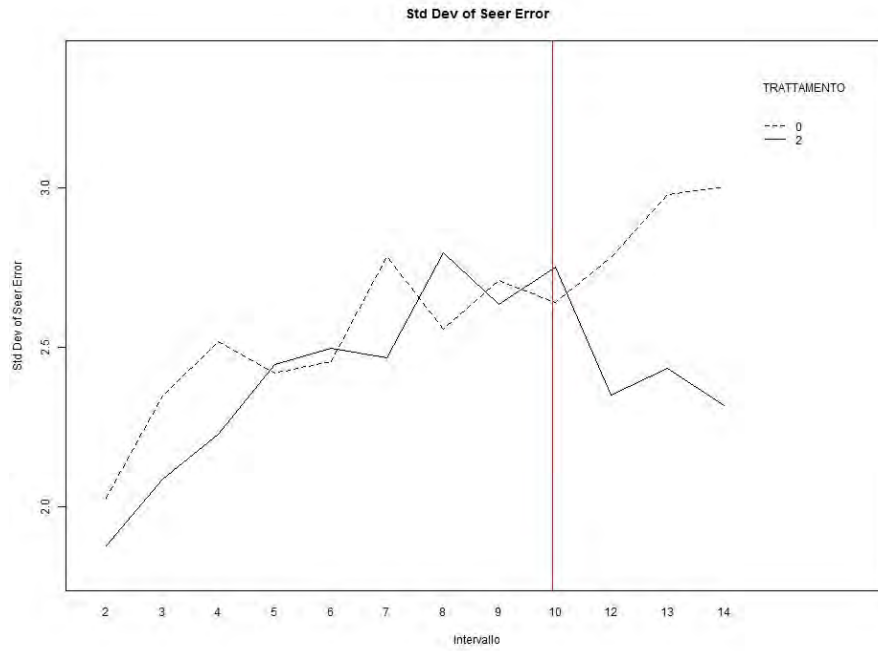
Figure 24: Std. Dev. of Steer Error: Cup of Coffee (2) vs Control (0).
Red line: moment of the administration.

Again, residual diagnostics were produced to verify if the model fitted properly with the dataset. The adoption of the reduced model did not produce an improvement in the quantile-quantile plot of residuals even if the values because the original model did not present any outliers (residual distance greater than 2.5). It implies that the original model had a very good capability in representing the dataset.
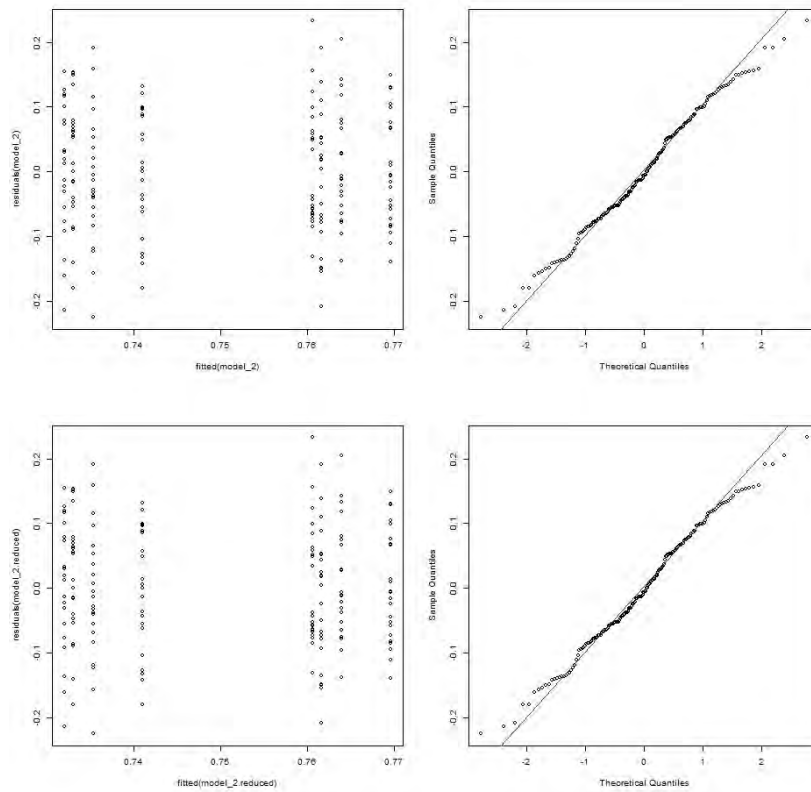
Figure 25: Residual diagnostics for the models before (upper diagrams) and after (lower diagrams) removal of data points with residual at distance greater than 2.5 standard deviations from zero. (Cup of Coffee)

3.2.2.3 Placebo Gum vs. Control

The characteristics of the group of subject administered with Placebo Gum are listed in Table 18

	Mean	Std. Dev.	Range
Age	24.46	2.47	20 - 29
Coffee per day	1.50	1.41	0 - 4

Table 18: Test deriver's characteristics: age and coffee. Placebo Gum group.

Subjective Sleepiness Evaluation (KSS)

A two-way ANOVA with Task Time (3 levels: before driving test, after 50 minutes, and after 70 minutes) and Administration (Placebo Gum and Control) as within-subject factors was performed on Karolinska Sleepiness

Scale index. Figure 26 and Table 19 show the variations observed in drivers' KSS scores.

Time	Control		Placebo Gum	
	Media	Std. Dev.	Media	Std. Dev.
1	3,67	1,35	3,38	1,24
2	5,24	1,97	5,19	1,75
3	4,95	1,80	4,14	1,24

Table 19: mean and Std. Dev. of drivers' KSS: before, during and after the guide. (Placebo Gum)

We found the effect of Placebo Gum during the tests with administration. In fact, since there is a growth in perception of sleepiness between before the test and after 50-minutes of driving (interval 1-2: $p < 0.001$), the score of KSS seems to return to the initial condition at the end of the driving session (intervals 1-3: $p = 0.203$). During the Control trials, the score of KSS increased during the first part of the trial (intervals 1-2: $p = 0.012$) and stayed on the same level during the last part of the driving session (intervals 2-3: $p = 0.854$).
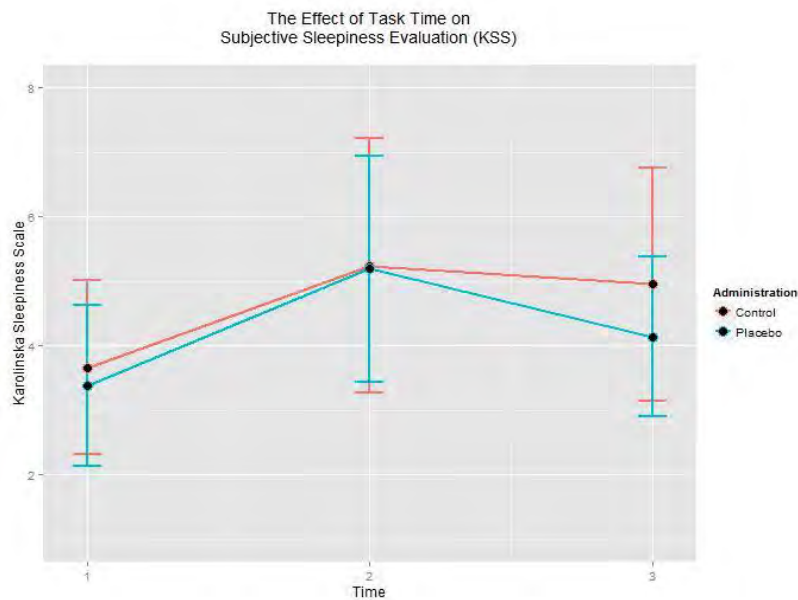
Figure 26: Karonlinska Sleepiness Scale score. (Placebo Gum)

Subjective Fatigue Evaluation (VAS)

A two-way ANOVA with Task Time (3 levels: before driving test, after 50 minutes, and after 70 minutes) and Administration (Cup of Coffee and Control) as within-subject factors was performed on Visual Analog Scale index. Table 20 and Figure 27 show the variations observed in drivers' VAS scores.

Time	Control		Placebo Gum	
	Media	Std. Dev.	Media	Std. Dev.
1	3,10	2,00	2,81	1,77
2	5,37	2,44	4,96	1,86
3	5,51	2,41	4,61	1,67

Table 20: mean and Std. Dev. of drivers' VAS: before, during and after the guide. (Placebo Gum)

We did not find the effect of Placebo Gum during the tests with administration. Indeed, there is a growth in perception of fatigue between before the test and after 50-minutes of driving (interval 1-2: $p < 0.001$), the score of VAS does stay at the same condition until the end of the driving session (intervals 2-3: $p = 0.800$; intervals 1-3: 0.005). Again, as for the Caffeinated Gum and Cup of Coffee experiments, the score of VAS increased during the first part of the trial (intervals 1-2: $p < 0.006$) and stayed on the same level during the last part of the driving session (intervals 2-3: $p = 0.979$).
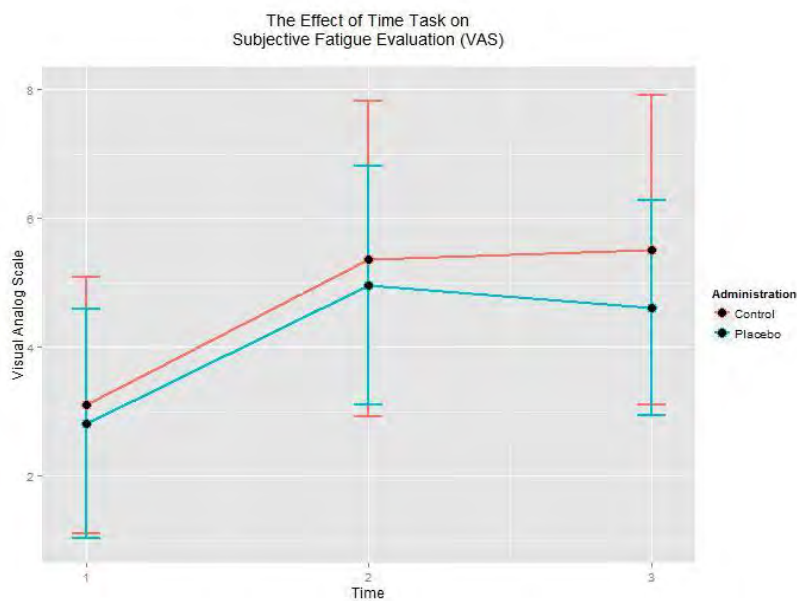
Standard Deviation of Lateral Position

A two-way ANOVA with Task Time (8 levels plus 3 levels) and Administration (Placebo Gum and Control) as within-subject factors was performed on variable Standard Deviation of Lateral Position. After the data-cleaning process, three trial from Control group had been discarded: in two trials an incidents occurred and one presented outlier data.

Table 21 lists the summary statistics (means and standard deviations) according to the administration.

Time.int	Control		Placebo Gum	
	Mean [m]	Std. Dev. [m]	Mean [m]	Std. Dev. [m]
2	0,266	0,047	0,271	0,084
3	0,291	0,073	0,293	0,096
4	0,306	0,090	0,295	0,090
5	0,295	0,078	0,308	0,113
6	0,318	0,096	0,299	0,111
7	0,342	0,108	0,302	0,096
8	0,318	0,082	0,319	0,097
9	0,327	0,085	0,324	0,114
10	0,335	0,067	0,326	0,109
12	0,348	0,069	0,329	0,144
13	0,332	0,079	0,324	0,109
14	0,324	0,069	0,338	0,115

Table 21: Std. Dev. of Lateral Position. Summary statistics. (Placebo Gum)

Since ANOVA hypothesis were rejected a Box-Cox data transformation had been implemented. As previously, interesting fact was to check if there was any differences before the administration. As we expected, the analysis showed that in the first part of the trial, before the administration, there was no significant differences between the two Administrations ($F(1,395)=2.645$, $p=0.105$), but there was a significant main effect of Task Time ($F(8,395)=2.042$, $p=0.041$).

After that, to check the efficacy of the Placebo Gum, an ANOVA for the "second" part of the trials was carried out. The analysis showed there

was not a significant main effect of the Administration (F(1,175)=1.647, p=0.201).
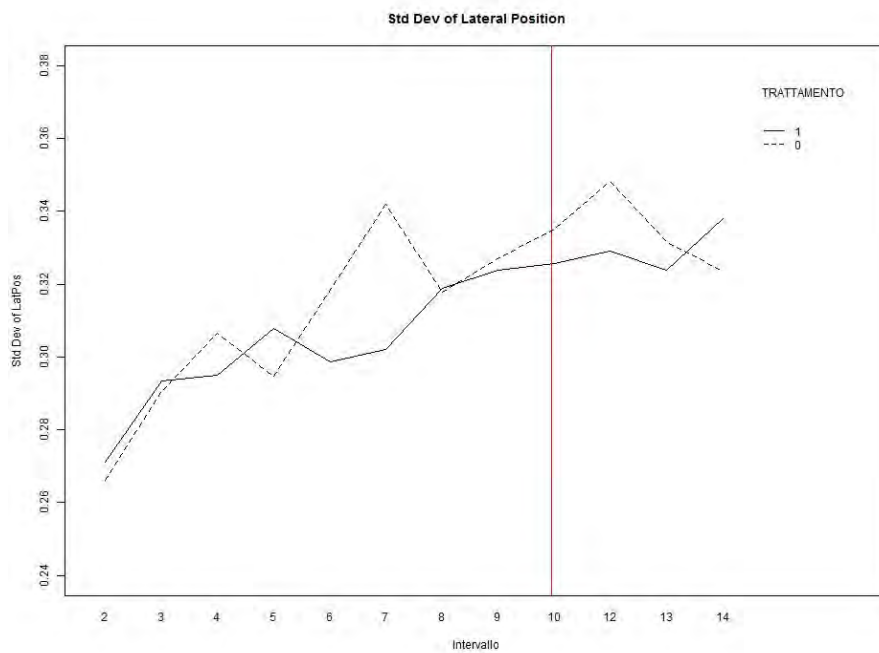
Figure 28: Std. Dev. of Lateral position: Placebo Gum (1) vs Control (0).
Red line: moment of the administration.

Finally, residual diagnostics were produced to verify if the model fitted properly with the dataset. The adoption of the reduced model produced an improvement in the quantile-quantile plot of residuals even if the values of parameters did not vary in a relevant manner from the original model. It implies that the original model had a good capability in representing the dataset.
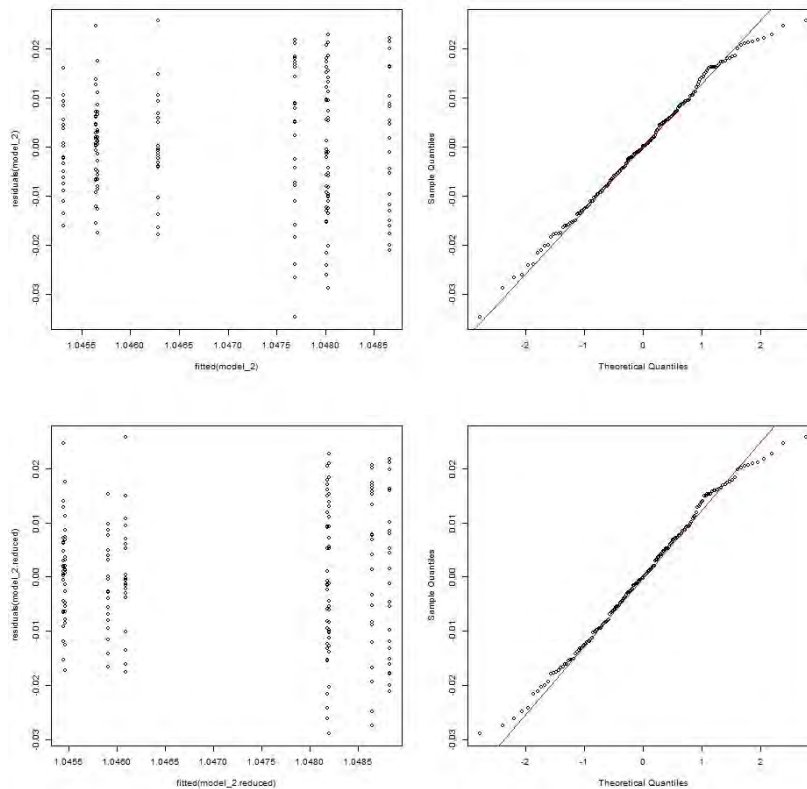
Figure 29: Residual diagnostics for the models before (upper diagrams) and after (lower diagrams) removal of data points with residual at distance greater than 2.5 standard deviations from zero. (Placebo Gum)

<u>Standard Deviation of Steer Error</u>

A two-way ANOVA with Task Time (8 levels plus 3 levels) and Administration (Placebo Gum and Control) as within-subject factors was performed on variable Standard Deviation of Steer Error. After the data-cleaning process, two trials from Control group had been discarded : in two trials an incidents occurred.

Table 22 lists the summary statistics (means and standard deviations) according to the administration.

Since ANOVA hypothesis were rejected a Box-Cox data transformation had been implemented. Again, first interesting fact was to check if there were any differences before the administration. As we expected, the analysis showed that in the first part of the trial, before the administration, there was a significant main effect of Task Time (F(8,404)=2.447, p=0.014). On the contrary to what we expected there was significant differences between the two Administrations (F(1,404)=12.544, p<0.001).

Time.int	Control		Placebo Gum	
	Mean [°]	Std. Dev. [°]	Mean [°]	Std. Dev. [°]
2	2,03	0,70	1,88	0,66
3	2,35	1,19	2,09	0,87
4	2,52	1,33	2,23	1,31
5	2,42	1,34	2,45	1,31
6	2,46	1,06	2,50	1,24
7	2,79	1,45	2,47	0,91
8	2,56	1,12	2,80	1,21
9	2,71	1,26	2,63	0,94
10	2,64	1,17	2,75	1,24
12	2,78	1,20	2,35	0,77
13	2,98	1,50	2,43	0,78
14	3,00	1,45	2,32	0,74

Table 22: Std. Dev. of Steer Error. Summary statistics. (Placebo Gum)

After that, to check the efficacy of the Placebo Gum, an ANOVA for the "second" part of the trials was carried out. Contrary on what we expected, the analysis showed the significant main effect of the Placebo Gum for the Standard Deviation of Steer Error ($F(1,179)=6.328$, $p=0.013$). This fact is probably attributed to previous differences before the administration of the Placebo Gum.
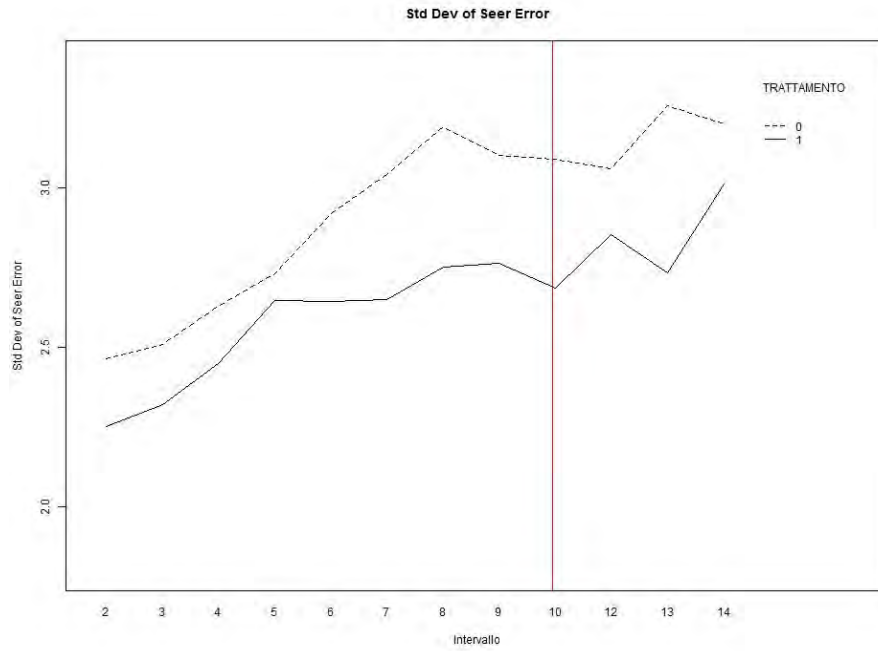
Figure 30: Std. Dev. of Steer Error: Placebo Gum (1) vs Control (0).
Red line: moment of the administration.

A residual diagnostics were produced to verify if the model fitted properly with the dataset. The adoption of the reduced model did not produce an improvement in the quantile-quantile plot of residuals even if the values because the original model did not present any outliers (residual distance greater than 2.5). It implies that the original model had a very good capability in representing the dataset.

Figure 31: Residual diagnostics for the models before (upper diagrams) and after (lower diagrams) removal of data points with residual at distance greater than 2.5 standard deviations from zero. (Placebo Gum)

3.2.2.4   Discussion

This dissertation demonstrates that one Caffeinated Chewing Gum (80 mg caffeine) significantly improves driving performance in short time (between 5 and 10 minutes), and a cup of coffee (80 mg caffeine) or a placebo (standard chewing gum) do not.

Both standard deviation of Lateral Position and standard deviation of Steer Error were improved in less than 10 minutes and they maintained the improvement until the end of the driving session.

The improvement in objective performance was accompanied by improvement in subjective assessments of sleepiness and fatigue. An average decrease of 1.5 points (out of 7) on the KSS was observed after the administration of caffeinated chewing gum as compared to its control group. The average VAS score significantly decreased from 5.74 to 4.35, where stayed on the same levels for both cup of coffee group (from 5.07 to 4.88) and placebo group (from 4.96 to 4.61). These findings are in

agreement with the pharmacokinetic profile of caffeine and what previously found in literature: "within 5 min approximately 85% of caffeine had been absorbed into the blood circulation system with the caffeine gum" [56].

Regarding the cup of coffee and the placebo chewing gum, they did not show any improvement to the standard deviation of the lateral position. On the contrary, they showed an improvement of the standard deviation of steer error, but something has to be discussed about that. Cup of coffee effect on the standard deviation of steer error can be considered minimal, in fact, even it is statistically significant, the difference is not as marked as for caffeinated chewing gum $(F(1,175)=4.075, p=0.045)$. Placebo Gum effect on standard deviation of steer error cannot properly be considered significant, because there was a significant difference between the control group and the "administered" group during the first part of the driving session, when the administration did not occurred yet. That fact is probably ascribable to that standard deviation of steer error is not the best driving performance indicator.

Conclusions

This dissertation analyses driver fatigue behavior and the effectiveness of caffeinated gum as countermeasure to fatigue. In particular, this study focuses on the passive task-related effect of highway driving in monotonous environment. Data collected with a driving simulator in laboratory were used to measure changes in driving performance. Self-perceived measure of fatigue and sleepiness were also measured.

Seventy-two subjects were asked to drive for 70 minutes along a straight road and they were administered with three different treatment: caffeinated chewing gum, cup of coffee, and placebo chewing gum. Thus, seventy-two subjects were divided in three groups of twenty-four, and each participant of every group had to take part in two driving sessions: one control driving test and one "administered" driving test.

The results were clear-cut:

- in accordance with previous studies, negative effect on driving performance of prolonged driving time was experimentally confirmed;

- in accordance with previous studies, the effectiveness of standard deviation of lateral positon and standard deviation of steer error in representing the worsening of driving performance was confirmed;

- the consumption of a regular cup of coffee (80 mg caffeine) does not improve driving performance in short time: until 20 minutes after the administration no significant improvement was observed;

- the absorption of caffeine with a caffeinated chewing gum (80 mg caffeine) improves driving performance in a relative short time: in

an interval between 5 and 10 minutes after the administration, significant improvements were observed;

- no effect by chewing regular chewing gum (no caffeine) on improving driving performance was observed.

Even though many studies on the effectiveness of caffeinated chewing gum in opposing fatigue and sleepiness have been done, this thesis work is the first attempt to study directly the effect of caffeinated chewing gum on driving performance and on reducing passive task-related driving fatigue. The advantages of assuming caffeine by caffeinated chewing gum are clear:

- rapid absorption, so if fatigue symptoms still persist after 10 minutes and drivers do not experience an improvement of the level of alertness, corresponding to a reduction of fatigue symptoms, then a second dose of chewing gum can be administered. This may be compared to a cup of coffee that would take about 35-45 minutes to make the decision to take a second dose;

- from a practical point of view, the advantage of caffeinated chewing gum is that it is small, portable, does not need to be taken with liquid.

Some interesting directions for future research are:

- extending the duration of the driving task after the administration, to investigate on the middle-long term effect of the chewing gum;

- changing the experimental design: a within-repeated-measure-experimental design would permit to make a direct comparison between the cup of coffee, placebo, and caffeinate chewing gum;

- testing the effect of the caffeinated chewing gum on a sleep restricted sample of subjects or during nighttime to investigate its effect on the sleep-related driving fatigue.

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Annex

A: Karolinska Sleepiness Scale (KSS)

The Karolinska Sleepiness Scale (KSS) [53] is a self-report measure of the level of subjective sleepiness an individual is experiencing. The KSS has been found to be a sensitive and reliable measure of sleepiness which has been validated against physiological measures. Individuals are required to indicate on a nine point Likert scale how sleepy they are currently feeling (Figure 32). Higher scores are indicative of higher levels of subjective sleepiness.

Advantages of KSS are: it is quick and easy to administer and many studies have used KSS and provide data comparison. Disadvantages are: it is easy to cheat and does not always reliably reflect objective performance measures.

Quale di queste affermazioni meglio descrive il Suo stato attuale (vigilanza/ sonnolenza)?

Estremamente vigile (sveglio)	1
Molto vigile (sveglio)	2
Vigile (sveglio)	3
Abbastanza vigile (sveglio)	4
Né vigile, né assonnato	5
Percepisco qualche segnale di sonnolenza	6
Assonnato, ma non mi sforzo per restare sveglio	7
Assonnato con un po' di fatica a restare sveglio	8
Molto assonnato, faccio molta fatica a restare sveglio	9

Figure 32: Karolinska Sleepiness Scale (KSS): Italian version.

B: Visual Analog Scale (VAS)

Sometimes called linear analogue scale, visual analog scale for fatigue is typically a 10 cm straight line with the end points labelled. Subjects have to place an "X", representing how they currently feel, along a visual analog line going from "Not fatigue" to "fatigue" as in Figure 33.

In contrast to discrete, Likert-type scales, the VAS places fewer restrictions on the range of responses available to individuals. However, the advantages of a visual analog scale are simplicity and sensitivity to small changes. Main disadvantages are that points along the line are not defined and comparison with other studies is difficult.

Marchi con una "X" il punto che, secondo lei, descrive il suo stato di affaticamento globale.

Per niente affaticato   Affaticato

Figure 33: Visual Analog Scale for fatigue: Italian version.

C: Simulator Sickness Questionnaire (SSQ)

The Simulator Sickness Questionnaire is the standard for measuring simulator sickness. It was developed by Kennedy [57] using over 1000 sets of data and through some analysis, they came up with a list of 27 symptoms experienced by users of virtual reality systems. The final SSQ is a self-report symptom checklist including the level of severity of the 16 symptoms that drivers are experiencing currently. For each of the 16 there are four levels of severity (none, slight, moderate, severe). Figure 34 is the sheet containing Simulator Sickness Questionnaire as administered.

SSQ – VERSIONE ITALIANA

NOME:	ID:
DATA:	ORARIO:

Somministrazione	PRE_____	POST-PROVA_____	FINALE_____

Sintomo	Nessuno	Leggero	Moderato	Forte
Malessere generale				
Fatica				
Mal di testa				
Affaticamento agli occhi				
Difficoltà di messa a fuoco				
Aumento della Salivazione				
Aumento della Sudorazione				
Nausea				
Difficoltà a concentrarsi				
"Sensazione di pesantezza alla testa"				
Visione confusa				
Capogiro (ad occhi aperti)				
Capogiro (ad occhi chiusi)				
Vertigini				
Fastidio di stomaco				
Aerofagia				
Altro (Descrivi)				

"Fastidio di stomaco" e' piu' leggero rispetto alla nausea

Figure 34: Simulator Sickness Questionnaire: Italian version.

3

D: Epworth Sleepiness Scale (ESS)

The Epworth Sleepiness Scale is a self-reported questionnaire with eight questions. It provides a measure of a general person's level of daytime sleepiness. It is the standard method for making this assessment.

The ESS asks individuals to rate their usual chance of dozing off or falling asleep in eight different situations or activities that most people engage in as part of their daily lives. The total ESS score is the sum of eight item-scores and can range between 0 and 24. The higher is the score, the higher is the probability of falling asleep during the day. The normal range defined by 5% confidence level is 0 to 10, with 2.8 as one standard deviation. Which means that subject with a score higher than 10 (with a tolerance to 13) should be discarded [58].

Che probabilità ha di appisolarsi o di addormentarsi nelle seguenti situazioni, indipendentemente dalla sensazione di stanchezza?

La domanda si riferisce alle usuali abitudini di vita dell'ultimo periodo.

Qualora non si sia trovato di recente in alcune delle situazioni elencate sotto, provi ad immaginare come si sentirebbe.

Usi la seguente scala per scegliere il punteggio più adatto ad ogni situazione.

0 = non mi addormento mai

1 = ho qualche probabilità di addormentarmi

2 = ho una discreta probabilità di addormentarmi

3 = ho un'alta probabilità di addormentarmi

Situazioni:

1	Seduto mentre leggo	_____
2	Guardando la TV	_____
3	Seduto, inattivo in un luogo pubblico (a teatro, ad una conferenza)	_____
4	Passeggero in automobile, per un'ora senza sosta	_____
5	Sdraiato per riposare nel pomeriggio, quando ne ho l'occasione	_____
6	Seduto mentre parlo con qualcuno	_____
7	Seduto tranquillamente dopo pranzo, senza aver bevuto alcoolici	_____
8	In automobile, fermo per pochi minuti nel traffico	_____
	Somma	_____

Grazie della collaborazione.

Figure 35: Epworth Sleepiness Scale: Italian version.

E: Driving simulator data sample output

F: R analysis code

```
#*********************************************************************************
#
#                        ANOVA sulla DEVIAZIONE STANDARD DELLA LATERAL POSITION
#                                   per intervalli di 5 minuti
#
#            tempo    0   5   10  15  20  25  30  35  40  45  50  55  60  65  70  75
#                     |---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|-->
#         intervallo  1   2   3   4   5   6   7   8   9   10  11  12  13  14  15
#
#*********************************************************************************


# //--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--
#                                    DATA READING
# //--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--

rm(list=ls())

# carico il file dati
dati<- read.table("300SEC_GOMMACAFFEINA.csv",header=T,sep=";", dec=",")
str(dati)

# rinomino le colonne
colnames(dati)<- c("ID","PROG_PROVA","ID_TEST","SCENARIO","TRATTAMENTO","TIME","DESC_TIME",
"AVG_SPEED","DS_SPEED","AVG_LATPOS","DS_LATPOS","AVG_LATACC","DS_LATACC","AVG_GAS","DS_GAS",
"AVG_STEER","DS_STEER","AVG_STEERSPEED","DS_STEERSPEED","AVG_STEERERROR","DS_STEERERROR")

# seleziono le colonne di rilievo ai fini dell'analisi
dati_1<- dati[c(1,2,3,5,6,11)]
dati_1<- subset(dati_1, (TIME<15 & TIME !=1 & TIME !=11 ))      # elimino gli intervalli 1 e 11

# ELIMINO ID CON DESIGN DIVERSO
dati_1<- subset(dati_1,(  ID != 283 &
                          ID != 289 &
                          ID != 285 &
                          ID != 284 ))


# ELIMINO TEST ANOMALI
dati_1<- subset(dati_1,(  ID_TEST != 1092 & # colpo di sonno a 53'
                          ID_TEST != 1093 & # incidente a 26'
                          ID_TEST != 1152 & # incidente a 50'
                          ID_TEST != 1153 & # incidente a 39'
                          ID_TEST != 1006 &
                          ID_TEST != 1205 &
                          ID_TEST != 1278 )) # incidente a 37'


parte_1<- subset(dati_1, (TIME<11))
parte_2<- subset(dati_1, (TIME>9)) # tengo conto anche dei 5 minuti antecedenti ai 50'


t<-table(dati_1$TRATTAMENTO)
t/12    # numero di prove effetuate per trattamento

# //--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--
#                                 DESCRIPTIVE STATISTICS
# //--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--

attach(dati_1)
mean_gomma<-with(dati_1,tapply(DS_LATPOS,list(TIME,TRATTAMENTO),mean))
sd_gomma<-with(dati_1,tapply(DS_LATPOS,list(TIME,TRATTAMENTO),sd))
sd_gomma[,1]
mean_gomma[,1]

characteristics_gommma<-data.frame(mean_gomma[,1],sd_gomma[,1],mean_gomma[,2],sd_gomma[,2])
characteristics_gommma

library(xlsx)
write.xlsx(characteristics_gommma, "car_gomma.xlsx")


# ---> Boxplot

jpeg(filename = "bp_latpos_gomma.jpg",
     width = 700, height = 523, units = "px",
     pointsize = 12,
     quality = 75,
     bg = "white", res = NA, family = "", restoreConsole = TRUE,
     type = c("windows", "cairo"))

boxplot(DS_LATPOS ~ TIME + TRATTAMENTO,
        main="Std. Dev. of Lateral Position for 5' interval",
```

```
        xlab="Time",
        ylab="Std. Dev. of Lateral Position",
        dati_1)
abline(v = 12.5, col="red")

dev.off()

# ---> Scatterplot

library(languageR)
library(lattice)

dati_1$TIME=factor(dati_1$TIME)
dati_1$TRATTAMENTO=factor(dati_1$TRATTAMENTO)
dati_1$ID=factor(dati_1$ID)

jpeg(filename = "tr_latpos_gomma.jpg",
     width = 858, height = 530, units = "px",
     pointsize = 12,
     quality = 75,
     bg = "white", res = NA, family = "", restoreConsole = TRUE,
     type = c("windows", "cairo"))

xyplot(DS_LATPOS ~ TIME | ID,
       type = "b",
       groups = TRATTAMENTO,
       xlab = "Intervallo",
       ylab = "Standard Deviation of Lateral Position",
       auto.key = T,
       dati_1)

dev.off()

xyplot(DS_LATPOS ~ TIME | as.factor(ID_TEST),
       type = "b",
       groups = TRATTAMENTO,
       xlab = "Intervallo",
       ylab = "Standard Deviation of Lateral Position",
       auto.key = T,
       dati_1)

################################################################
#       TEST - REGRESSIONE

jpeg(filename = "reg_latpos_gomma.jpg",
     width = 858, height = 530, units = "px",
     pointsize = 12,
     quality = 75,
     bg = "white", res = NA, family = "", restoreConsole = TRUE,
     type = c("windows", "cairo"))

xyplot(DS_LATPOS ~ TIME | ID,
       type = c('p','r'),
       groups = TRATTAMENTO,
       xlab = "Intervallo",
       ylab = "Standard Deviation of Lateral Position",
       auto.key = T,
       dati_1)

dev.off()

################################################################


# //--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--
#                                          BOX-COX DATA MOD
# //--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--

# CAMPIONE TOTALE

attach(dati_1)
dati_1$TIME=factor(dati_1$TIME)
dati_1$TRATTAMENTO=factor(dati_1$TRATTAMENTO)

library(MASS)
boxcox (DS_LATPOS ~ TIME, lambda = seq(-0.4, -0.1, 0.05))

# elevo per il valore di lambda che massimizza la log-massimo verosimilianza e introduco
# la variabile intensity e verifico con TEST la Normalità

DS_LATPOS_d1<- DS_LATPOS^(-0.25)
shapiro.test(DS_LATPOS_d1)

# Test parametrico (Levene) - Più robusto rispetto alla violazione della normalità
#
```

```r
# Se p-value > 0.05 l'ipotesi di Omoschedasticità è verificata
# I dati sono omoschedastici nei gruppi considerati = OK!

library(car)
leveneTest(DS_LATPOS_d1 ~ TIME, data = dati_1)

detach(dati_1)


# PRIMA PARTE

attach(parte_1)

parte_1$TIME=factor(parte_1$TIME)
parte_1$TRATTAMENTO=factor(parte_1$TRATTAMENTO)

# Provo a modificare l'output,  non normale
library(MASS)
boxcox (DS_LATPOS ~ TIME, lambda = seq(-0.5, 0, 0.05))

# elevo per il valore di lambda che massimizza la log-massimo verosimilianza e introduco
# la variabile intensity e verifico con TEST la Normalità

DS_LATPOS_p1<- DS_LATPOS^(-0.15)
shapiro.test(DS_LATPOS_p1)

# Test parametrico (Levene) - Più robusto rispetto alla violazione della normalità
#
# Se p-value > 0.05 l'ipotesi di Omoschedasticità è verificata
# I dati sono omoschedastici nei gruppi considerati = OK!

library(car)
leveneTest(DS_LATPOS_p1 ~ TIME, data = parte_1)

detach(parte_1)


# SECONDA PARTE

attach(parte_2)

parte_2$TIME=factor(parte_2$TIME)
parte_2$TRATTAMENTO=factor(parte_2$TRATTAMENTO)

# Provo a modificare l'output,  non normale
library(MASS)
boxcox (DS_LATPOS ~ TIME, lambda = seq(-1, 0, 0.05))

# elevo per il valore di lambda che massimizza la log-massimo verosimilianza e introduco
# la variabile intensity e verifico con TEST la Normalità

DS_LATPOS_p2<- DS_LATPOS^(-0.4)
shapiro.test(DS_LATPOS_p2)

# Test parametrico (Levene) - Più robusto rispetto alla violazione della normalità
#
# Se p-value > 0.05 l'ipotesi di Omoschedasticità è verificata
# I dati sono omoschedastici nei gruppi considerati = OK!

library(car)
leveneTest(DS_LATPOS_p2 ~ TIME, data = parte_2)

detach(parte_2)




# //--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--
#
#                                 ANOVA SU DATI NON MODIFICATI BOC-COX
#
# //--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--


# ------------------------------------------------------------------------------------------
#                   Studio dell'interazione tra TIME, TRATTAMENTO
# ------------------------------------------------------------------------------------------
attach(dati_1)
inter <- aov(DS_LATPOS ~ TRATTAMENTO*TIME, data=dati_1)
anova(inter)

# se p-value > 0.05 non è significativo

plot(TukeyHSD(inter, "TIME"))
plot(TukeyHSD(inter, "TRATTAMENTO"))
```

```r
jpeg(filename = "int_latpos_gomma.jpg",
     width = 950, height = 709, units = "px",
     pointsize = 12,
     quality = 75,
     bg = "white", res = NA, family = "", restoreConsole = TRUE,
     type = c("windows", "cairo"))

interaction.plot( TIME,
                  TRATTAMENTO,
                  DS_LATPOS,
                  xlab="Intervallo",
                  ylab="Std Dev of LatPos",
                  ylim=c(0.24,0.38),
                  main="Std Dev of Lateral Position")
abline(v = 8.95, col= "red")

dev.off()

# se i segmenti sono paralleli (o quasi) non vi è interazione

detach(dati_1)


# //////////////////////////////////////////////////////////////////////////////////
# //////////////////////////////////////////////////////////////////////////////////
# //////////////////////////////////////////////////////////////////////////////////
# //////////////////////////////////////////////////////////////////////////////////


# //--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--
#
#                                ANOVA SU DATI MODIFICATI BOC-COX
#
# //--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--


# //--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--
#                        Per intervalli di 5 minuti studio sul totale:
#                  EFFETTO DEL TEMPO + PROG_PROVA CON TRATTAMENTO FISSO
# //--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--
attach(dati_1)

dati_1$TIME=factor(dati_1$TIME)
dati_1$TRATTAMENTO=factor(dati_1$TRATTAMENTO)
dati_1$ID=factor(dati_1$ID)

dati_1$DS_LATPOS <- DS_LATPOS_d1
dati_1$DS_LATPOS


# ------------------------------------------------------------------------------------
#                   Studio dell'interazione tra TIME, TRATTAMENTO
# ------------------------------------------------------------------------------------

inter <- aov(DS_LATPOS_d1 ~ TRATTAMENTO*TIME, data=dati_1)
anova(inter)

inter2 <- aov(DS_LATPOS_d1 ~ TRATTAMENTO*TIME, data=dati_1, subset=abs(scale(resid(inter)))<2.5)


interaction.plot( TIME,
                  TRATTAMENTO,
                  DS_LATPOS,
                  xlab="Intervallo",
                  ylab="Std Dev of LatPos",
                  ylim=c(0.24,0.38),
                  main="Std Dev of Lateral Position")
                  abline(v = 8.95, col= "red")


# se i segmenti sono paralleli (o quasi) non vi è interazione


# ------------------------------------------------------------------------------------
#                ANOVA prova totale con trattamento fisso: effetto del solo TEMPO
# ------------------------------------------------------------------------------------


modello0TOT <- aov(DS_LATPOS ~ TIME,
                   data=subset(dati_1, TRATTAMENTO == 0))       # fit del modello lineare
anova(modello0TOT)                                                          # tabella ANOVA
```

```
TukeyHSD(modello0TOT, "TIME", ordered=TRUE)
plot(TukeyHSD(modello0TOT, "TIME", ordered=TRUE))

modello3TOT <- aov(DS_LATPOS ~ TIME,
                   data=subset(dati_1, TRATTAMENTO == 3))        # fit del modello lineare
anova(modello3TOT)                                                               # tabella ANOVA

TukeyHSD(modello3TOT, "TIME", ordered=TRUE)
plot(TukeyHSD(modello3TOT, "TIME", ordered=TRUE))




detach(dati_1)



# //--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--
#                             Per intervalli di 5 minuti studio:
#                                  ANOVA SUI PRIMI 50 MINUTI
# //--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--

attach(parte_1)
parte_1$TIME=factor(parte_1$TIME)
parte_1$TRATTAMENTO=factor(parte_1$TRATTAMENTO)
parte_1$ID=factor(parte_1$ID)

parte_1$DS_LATPOS <- DS_LATPOS_p1
#parte_1$DS_LATPOS

# ---> effetto del TIME + TRATTAMENTO

model_1 <- aov(DS_LATPOS ~ TRATTAMENTO + TIME , data= parte_1)
anova(model_1)

model_1.reduced <- aov(DS_LATPOS ~ TRATTAMENTO + TIME, data=parte_1, subset=abs(scale(resid(model_1)))<2.5)
anova(model_1.reduced)

jpeg(filename = "diagnostic.p1_latpos_gomma.jpg",
     width = 950, height = 950, units = "px",
     pointsize = 12,
     quality = 75,
     bg = "white", res = NA, family = "", restoreConsole = TRUE,
     type = c("windows", "cairo"))

par(mfrow=c(2,2))
plot(fitted(model_1), residuals(model_1))
qqnorm(residuals(model_1),main="")
qqline(residuals(model_1), col="red")
plot(fitted(model_1.reduced), residuals(model_1.reduced))
qqnorm(residuals(model_1.reduced),main="")
qqline(residuals(model_1.reduced),col="red")
par(mfrow=c(1,1))

dev.off()

detach(parte_1)




# //--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--
#                                  Per intervalli di 5 minuti:
#                     DIFFERENZA TRA I TRATTAMENTI NEGLI ULTIMI 15 MINUTI
#                          (ho incluso da dopo i 45', compresi i 50'->55')
# //--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--//--\\--

attach(parte_2)
parte_2$TIME=factor(parte_2$TIME)
parte_2$TRATTAMENTO=factor(parte_2$TRATTAMENTO)
parte_2$ID=factor(parte_2$ID)

parte_2$DS_LATPOS <- DS_LATPOS_p2
#parte_2$DS_LATPOS

model_2 <- aov(DS_LATPOS ~ TRATTAMENTO + TIME , data= parte_2)
anova(model_2)

model_2.reduced <- aov(DS_LATPOS ~ TRATTAMENTO + TIME, data=parte_2, subset=abs(scale(resid(model_2)))<2.5)
anova(model_2.reduced)

jpeg(filename = "diagnostic.p2_latpos_gomma.jpg",
     width = 950, height = 950, units = "px",
     pointsize = 12,
     quality = 75,
     bg = "white", res = NA, family = "", restoreConsole = TRUE,
```

```
    type = c("windows", "cairo"))

par(mfrow=c(2,2))
plot(fitted(model_2), residuals(model_2))
qqnorm(residuals(model_2),main="")
qqline(residuals(model_2), col="red")
plot(fitted(model_2.reduced), residuals(model_2.reduced))
qqnorm(residuals(model_2.reduced),main="")
qqline(residuals(model_2.reduced),col="red")
par(mfrow=c(1,1))

dev.off()

# -------------------------------------------------------------------------------------------
#                    ANOVA parte finale con trattamento fisso: effetto del solo TEMPO
# -------------------------------------------------------------------------------------------


modello0f <- aov(DS_LATPOS ~ TIME,
data=subset(parte_2, TRATTAMENTO == 0)) # fit del modello lineare
anova(modello0f)                                                        # tabella ANOVA
model.tables(modello0f)

modello3f <- aov(DS_LATPOS ~ TIME,
data=subset(parte_2, TRATTAMENTO == 3)) # fit del modello lineare
anova(modello3f)                                                        # tabella ANOVA
model.tables(modello3f)



# -------------------------------------------------------------------------------------------
#                         Confronto differenze tra intervalli singoli
# -------------------------------------------------------------------------------------------

# INTREVALLO 12

modello_12 <- aov(DS_LATPOS ~ TRATTAMENTO,
data=subset(parte_2, TIME == 12))        # fit del modello lineare
anova(modello_12)                                                      # tabella ANOVA
model.tables(modello_12)

plot(TukeyHSD(modello_12, "TRATTAMENTO", ordered=TRUE))


# INTREVALLO 13

modello_13 <- aov(DS_LATPOS ~ TRATTAMENTO,
data=subset(parte_2, TIME == 13))        # fit del modello lineare
anova(modello_13)                                                      # tabella ANOVA
model.tables(modello_13)

plot(TukeyHSD(modello_13, "TRATTAMENTO", ordered=TRUE))


# INTREVALLO 14

modello_14 <- aov(DS_LATPOS ~ TRATTAMENTO,
data=subset(parte_2, TIME == 14))        # fit del modello lineare
anova(modello_14)                                                      # tabella ANOVA
model.tables(modello_14)

plot(TukeyHSD(modello_14, "TRATTAMENTO", ordered=TRUE))

################################################################################################
################################################################################################
################################################################################################



################################################################################################

##     GRAFICI

################################################################################################
################################################################################################
####################            RUN FIRST           ###########################################
################################################################################################
################################################################################################

library(ggplot2)

## Gives count, mean, standard deviation, standard error of the mean, and confidence interval (default 95%).
##   data: a data frame.
##   measurevar: the name of a column that contains the variable to be summariezed
```

```r
##   groupvars: a vector containing names of columns that contain grouping variables
##   na.rm: a boolean that indicates whether to ignore NA's
##   conf.interval: the percent range of the confidence interval (default is 95%)
summarySE <- function(data=NULL, measurevar, groupvars=NULL, na.rm=FALSE,
                      conf.interval=.95, .drop=TRUE) {
    library(plyr)

    # New version of length which can handle NA's: if na.rm==T, don't count them
    length2 <- function (x, na.rm=FALSE) {
        if (na.rm) sum(!is.na(x))
        else       length(x)
    }

    # This does the summary. For each group's data frame, return a vector with
    # N, mean, and sd
    datac <- ddply(data, groupvars, .drop=.drop,
                   .fun = function(xx, col) {
                       c(N    = length2(xx[[col]], na.rm=na.rm),
                         mean = mean    (xx[[col]], na.rm=na.rm),
                         sd   = sd      (xx[[col]], na.rm=na.rm)
                       )
                   },
                   measurevar
    )

    # Rename the "mean" column
    datac <- rename(datac, c("mean" = measurevar))

    datac$se <- datac$sd / sqrt(datac$N)  # Calculate standard error of the mean

    # Confidence interval multiplier for standard error
    # Calculate t-statistic for confidence interval:
    # e.g., if conf.interval is .95, use .975 (above/below), and use df=N-1
    ciMult <- qt(conf.interval/2 + .5, datac$N-1)
    datac$ci <- datac$se * ciMult

    return(datac)
}

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tgc <- summarySE(dati_1, measurevar="DS_LATPOS", groupvars=c("TRATTAMENTO","TIME"))
tgc

last3<-subset(tgc, (as.integer(TIME) > 9))
last3

library(xlsx)
write.xlsx(last3, "sd_latpos03.xlsx")


pd <- position_dodge(0.5) # move them .05 to the left and right

dati_1$TRATTAMENTO = factor(dati_1$TRATTAMENTO)

ggplot(tgc, aes(x=TIME, y=DS_LATPOS,colour=TRATTAMENTO)) +
    geom_errorbar(aes(ymin=DS_LATPOS-ci/2, ymax=DS_LATPOS+ci/2), width=1.5, position=pd) +
    geom_line(position=pd) +
    geom_point(position=pd, size=4, shape=21, fill="black") + # 21 is filled circle
    xlab("Time") +
    ylab("Std. Dev. of Gas") +
      scale_colour_hue(name="TRATTAMENTO",    # Legend label, use darker colors
                     breaks=c("0","3"),
                     labels=c("Control", "Caff. Gum"),
                     l=40) +                          # Use darker colors, lightness=40
    ggtitle("The Effect of Fatigue on\nStd. Dev. of Lateral Position") +
#   expand_limits(y=0) +                              # Expand y range
#   scale_y_continuous(breaks=0:20*1) +        # Set tick every 4
    theme_bw() +
    theme(legend.justification=c(1,0),
          legend.position=c(1,0))                  # Position legend in bottom right
```