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CICLO XXX

Study of motorcyclist's behaviour during emergency braking in the perspective of training for safety

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"Allí comprendimos que nuestra vocación, nuestra verdadera vocación, era andar eternamente por los caminos y mares del mundo."

- Ernesto Che Guevara - Notas de viaje: diario en motocicleta

Abstract

The main aim of the PhD activity here presented is to understand PTW's riders behaviour in risky scenarios, when the time to collision is short and evasive manoeuvers are required. This research focus on the identification of the key components of control skills, together with perception skills, required for a high performance and also for effective training interventions that can reduce the number of PTW collisions or mitigate their consequences. Preliminary results from this research based on in-depth accident data revealed collision at intersections as one of the biggest threats to motorcyclists and weak braking during emergency events as one of the most common reactions. Furthermore, the first part of the research showed that different patterns can be identified among riders after analyzing two naturalistic studies from riders on Powered Two Wheelers scooter-style in Florence and cyclists on e-bike in Gothenburg.

The thesis presents a procedure designed to study the performance of riders in emergency situations based on: interaction with a constantly changing environment, dynamics of a two-wheeled vehicle, and capability of the rider. Results from field experiments in a controlled scenario with riders of different level of competencies revealed that the procedure defined can detect patterns from high skilled riders different from low skilled riders. In addition, the results provided key values that can be used to level skill classification. The characterization of the patterns of the riders of different skills is presented including two models, one that predicts the braking performance and another model that estimates the risk of loss control of the rider, both based on the rider's interaction with the vehicle. Finally a tool interface based on the performance models is designed to support training tasks prescribing objective feedback to the riders to enhance training for safety. The thesis presents some directions for future research in skills acquisition, naturalistic studies and applications for training that stem from the results. Furthermore, the outcomes of this research can support providing insights for future designs of safety systems, such as advanced braking systems tailored to the patterns of each rider.

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Preface

The work of this research was mostly conducted within the activity of the European project MOTORIST, funded by the 7th Framework Program of the European Commission within the Marie Curie Innovative Training Network (MOTOrcycle Rider Integrated SafeTy, grant agreement n. 608092). The *Dipartimento di Ingegneria Industriale* of the Università degli Studi di Firenze was coordinator and member of the MOTORIST consortium, together with TU Delft, University of Padova, University of West Bohemia, Université de Strasbourg, Ludwig-Maximilians-Universitaet Muenchen, Siemens Industry Software NV, Dainese S.p.A. and the supervisory board of ACEM, FEMA, ESI group, MOOG and SWOV.

The aim of MOTORIST project was to make the use of PTWs safer enhancing and optimizing the methods for rider training, developing active safety systems that improve the rider-PTW interaction and investigating design and materials for personal protective equipment. This work corresponds to the activities done in Work Package1 aiming to support training activities for motorcyclists with studies derived from in-depth accident data, from naturalistic data, and from a quantification of rider behaviour in critical situations. The methods and findings of the present research do not necessarily coincide with the official results of MOTORIST project.

1. Introduction

1.1. Context of the Study

Each year, about 1.25 million people die as a result of road traffic crashes, and nearly a quarter of all road traffic deaths are among motorcyclists (World Health Organization, 2015) (Figure 1-1). Although fatality and injury rates have decreased in the last years, road users are increasing year by year and, as a consequence, fatality and injury numbers have gone up.

Around 313 million powered two-wheelers (PTW) - also known as two-wheel motor vehicles (TWMV) - circulated in the world in 2008. In Europe, the fleet of PTW in 2011 was 37 million vehicles, of which about 70% were motorcycles and 30% were mopeds (ACEM, 2013). In large cities, the needs for urban mobility has increased the presence of PTW in the last years with cities like Barcelona that rose from 24.7% to 30.2% of the motorized vehicle fleet between 2002 and 2011. These proportion are much higher in most of the Asian countries, where the PTWs are the main mode of transport, accounting for up 85% (OECD/ITF, 2015).

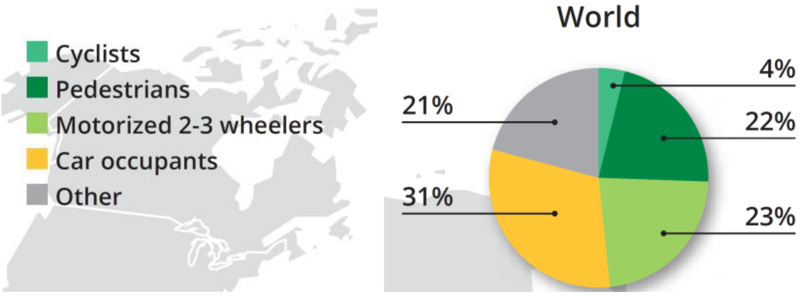


Figure 1-1 Road Fatalities in the World by transport mode. (Source: WHO, 2015)

Riders of PTW are exposed to significantly higher accident and injury risk compared to drivers of four-wheeled vehicles, as a result of their inherent lower stability, less conspicuity and higher vulnerability because the lack of protection of an enclosed vehicle. In the EU, the motorcyclists make up 15% of all who die on the road (OECD/ITF, 2015). The fatalities have been reduced in the last years but the increase of safety has been insufficient, and low compared to the improvement of other modes of transport like cars (Figure 1-2). The number of motorcyclists' deaths per registered motorcycle in the EU is more than two times higher compared to car occupant deaths per registered car (11 per 100 000 versus 5 per 100 000) (European Commission, 2015), and this rate is much higher in countries like the US where the fatality rate per registered vehicle for motorcyclists in 2015 was six times the rate for passenger car occupants (NHTSA, 2016). The ratio increases dramatically (27 times in USA) when comparing per distance traveled.

In addition to the irreplaceability of human lives lost in fatal crashes, a study of the NHTSA estimated that the economic costs of motor vehicle crashes in 2010 (including lost productivity, medical costs, legal and court costs, emergency service costs, insurance administration costs, congestion costs, property damage, and workplace losses) was $242 billion that represents the equivalent of 1.6 percent of the real U.S. Gross Domestic Product (Blincoe, Miller, Zaloshnja, & Lawrence, 2015).

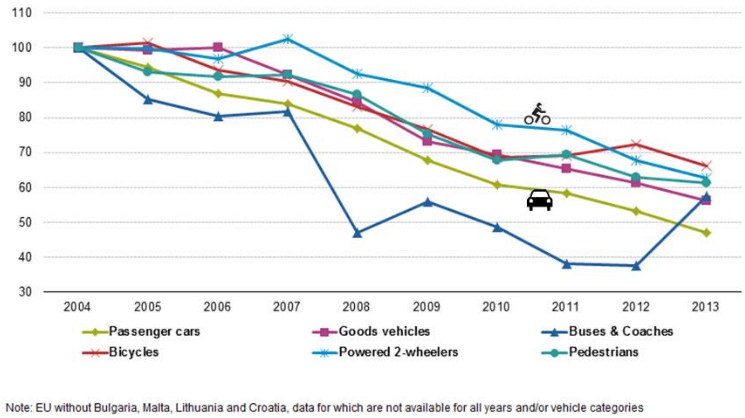


Figure 1-2. Evolution of the number of fatalities between 2004 and 2013, index base 100=2004. Source: (European Commission (Directorate-General for Mobility and Transport), 2016)

Riding may be perceived as an easy process based on the number of PTW users that can be found on the roads, however riding activity is one of the most demanding daily tasks that humans perform. Riding is a complex decision-making process because of the dynamic nature of various components such as the rider, the vehicle and environment and their interrelated characteristics. Moreover the capabilities of the riders are influenced by dynamic context such as age, experience and mental, physical and emotional state (Mitrović, 2005). One of the reasons for the high ratio of crashes of PTW rider's along the years, even with added safety features of vehicles, protective equipment and infrastructure is that the training methods and, as a consequence the competency of riders, have not necessarily improved.

The MAIDS in-depth study of PTW accidents in Europe revealed that human factors failures are predominant as the main causations in PTW riders' accident with 87.9% of all cases. Other vehicle drivers were mostly responsible of this human factor failures (50.5% of the cases) mainly related with perception failure, but PTW riders' failures still represents 37.4% of the main causes with poor perception of danger and poor traffic analysis as the most frequent errors (ACEM, 2009). Scientific based countermeasures are necessary to mitigate fatalities and injuries aiming at improving riding competencies and behaviour (training, licensing and sensitization campaigns). Training is also perceived as a need from PTW users. In a survey with 6297 frequent riders from over 10 countries Beanland et al. (Beanland, Lenné, et al., 2013) revealed that many riders seemed to give greater importance on rider training than assistive system. Riders from the survey had the "*perception that assistive technologies may* *lead to careless or lazy riding and that they do not improve understanding of vehicles' technical limitations"* (Beanland, Lenné, et al., 2013). However, riding activity has been poorly studied, and most of the studies have focused on observing behaviour more than aiming at understanding the observed behaviours.

1.2. Problem Statement

Despite the consensus among the stakeholder about the importance of the training as countermeasure to reduce accidents, there is little evidence about the effectiveness of the training programs. In fact, current literature suggests that the majority of training programs have questionable effectiveness in crash reduction (Kardamanidis, Martiniuk, Ivers, Stevenson, & Thistlethwaite, 2010).

The behavioural qualities relevant for safe driving were identified in the GDE (Goals for Driver Education) Matrix (Hatakka, Keskinen, Gregersen, Glad, & Hernetkoski, 2002) and then assigned to a model in four hierarchically-ordered behavioural levels:

- Operational level (manoeuvring the vehicle)
- Tactical level (acting in accordance with traffic conditions)
- Strategic level (selecting journeys/trips and factors related to journeys/trips)
- General level (personal characteristics, ambitions and competencies)

This GDE Matrix has been widely accepted and frequently has become the base of the national training programs. However, the tests to obtain the riding license are limited to simple tests that examine part of the program. Since higher order skills take longer to be assimilated and the main goal of users of riding schools is to get the license, in most cases riding schools are committed to train the riders mainly to perform properly the tests (Aupetit, 2010), without time and budget to explore in more depth all the levels. Fuller (Fuller, 1984) in his avoidance model of the driver behaviour defined two stages previous to the collision when confronted with a potential aversive stimuli: "anticipatory avoidance response" and "delayed avoidance response". A simple representation of the model is showed in Figure 1-3. While anticipatory avoidance response are the key to minimize traffic conflicts, complex traffic environments together with conspicuity issues of the PTW riders may bring to unpredicted scenarios requiring an evasive manoeuver in a very limited time.

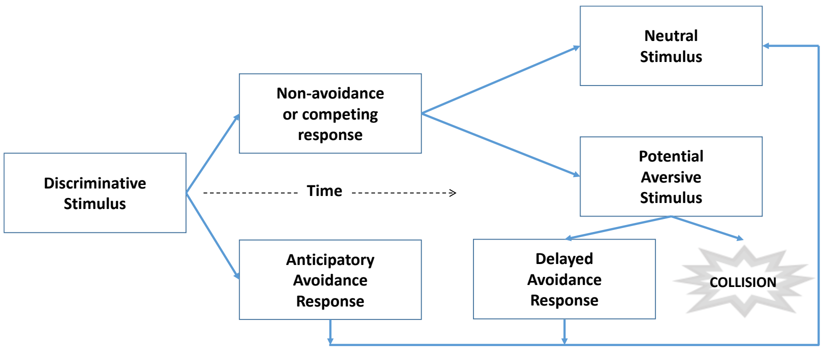


Figure 1-3. Simple Avoidance Analysis. Source: (Fuller, 1984)

One of the main issues of the current training is the absence of real-world controlled scenarios to test rider competencies. In most cases training is carried out in unrealistic “aseptic” environments (Aupetit, Gallier, Riff, Espié, & Delgehier, 2016; Aupetit, Riff, Buttelli, & Espié, 2013), relying on exercises that artificially separate control skill actions and hazard perception, not sufficient to assess the ability to safely ride in traffic (OECD, 2015).

Another critical aspect of the current training is the absence of means to measure in an objective way the rider’s competencies, what reduces the chances of setting detailed targets to the trainees. During the tests for licensing “*the assessment of driving skills takes place under such varied conditions that a certain subjective judgment cannot be avoided, even though nationwide assessment criteria are used combined with coordination of the examiners*” (OECD, 2015). Hollnagel & Woods (2005) identified two characteristics to define the range of measurement employed normally in empirical research: first, how easy is to make the measurement; and second, how meaningful the measurement is (i.e. how easy and how valid is the interpretation). Current assessment of rider competencies is mainly based on expert criteria of the trainers during observations, a measurement easy to make but with a weak validity of interpretation. Figure 1-4 shows an example of typical measurements on the two dimensions identified. New approaches, including available technology, are necessary to improve the understanding of the riding behaviour and capacities.

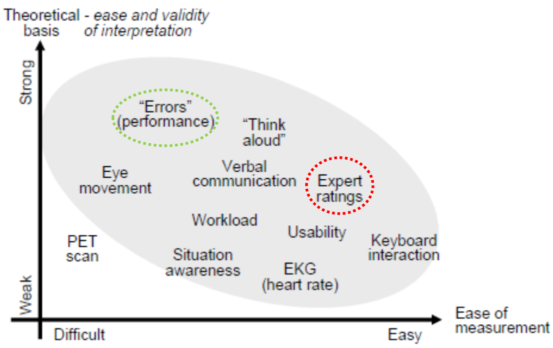


Figure 1-4. Dimensions of Measurements. Source: (Hollnagel & Woods, 2005)

Collisions with other vehicles represent the biggest threat to PTW riders, and while emergency braking is the most frequently evasive manoeuvre required in PTW riding (Penumaka, Savino, Baldanzini, & Pierini, 2014; Sporner & Kramlich, 2001), it has also been reported as the most difficult manoeuver to learn (Dewar, Rupp, Gentzler, & Mouloua, 2013). Despite the fact that the multiple vehicle collision with motorcycles are caused more often by other road users (ACEM, 2009; Hurt, Ouellet, & Thom, 1981) there are signs to think that motorcycle riders might have reduced the crashes if they had perceived earlier the hazard and if they had performed the braking manoeuver correctly. Braking is a complex perceptual motor task that requires timely application of properly proportioned front and rear brake pressure, in proper correspondence with variations in road friction and vehicle stability. Because of difficult task of braking in emergency situations, many riders fail to perform it adequately due to constraints on response time precipitated by failures of perception, cognition and control actions (Penumaka et al., 2014; Sporner & Kramlich, 2001). In emergency situations, when the time to react is limited and riders are under high stress or panic, braking properly becomes critic and extremely difficult. The correct performance of emergency braking depends on quick and accurate hazard perception, knowledge about the proper way of braking and automatisms to react in the shortest time and with the correct execution. Effective rider training methods are necessary for the development of adequate braking proficiency (integrating perception and control skills) in response to emergency situations to achieve the goal of increasing safety and reducing crashes and their fatal consequences.

1.3. Scope and specific aims

This thesis seeks to understand PTW's riders behaviours in risky scenarios, when the time to collision is too short and evasive manoeuvers are required. This research will focus on the identification of the key components of control skills, together with perception skills, required for effective training interventions that can reduce the number of PTW collisions or mitigate their consequences. The aims of this research are the following:

- Understanding the skills/competencies required to reduce accidents in most risky scenarios.
- Studying the behaviour and performance of braking as the most relevant evasive manoeuvre.
- Design of realistic scenario coupling control and hazard perception skills for training
- Definition of objective key parameters associated with the level of control skill competencies during emergency braking.
- Quantitative characterization of the human riding skills applied to braking scenario.
- Development of an interface tool with objective feedback to support learning process.

1.4. Significance of the Study

Previous research that suggested that training is ineffective in reducing PTW crash risk are opposed to the research in skill acquisition/expertise that shows that deliberate specific practice improves skill (Ericsson, 2004). The failure of examined training methods could be due to poorly designed training paradigms that do not effectively target and engage the processes underlying the desired learning outcomes. Thus, evasive manoeuvers training must not address only mechanical braking control, but exploit the natural integration of perception and action of real-world emergency scenarios. On the other side, other types of training focus on hazard perception, but decoupled from the reaction component, i.e. the ability to respond quickly and effectively in unpredicted traffic conflicts. Understanding how high skilled riders and less skilled riders interact with vehicle and environment will provide key insights to generate specific and accurate instructions in training for safety. Improved braking skill will mean riders perceive hazards earlier, respond more appropriately, and brake sooner in a shorter stopping distance, reducing collision and/or injury severity risk.

This thesis proposes a more appropriate skill testing/training paradigm that exploits a closer similitude with the real world, including rider-vehicle-environment interaction, by maintaining the natural coupling of perception (higher order skill) and action (vehicle maneuvering) inherent in any emergency event. For this purpose the study has generated a realistic yet controlled scenario based on in-depth data cases of accidents to carry out the field experiments. Analysis of response timing and braking patterns will inform design of training interventions and of technology to support learning. Moreover, the understanding of the rider behaviour represents insights for the design and development of safety Intelligent Transport Systems (ITS) and the improvement of braking systems.

1.5. Overview of the Study

The thesis is organized as follows:

Chapter 1 is the introduction of the research carried during this activity defining the context of the study and the aims of the research. Chapter 2 summarizes a state of the art analysis of the current licensing training, the effectiveness of the different training methods, the skills associated with the riding task, and provides an overview of the literature about studies of braking performance with powered two wheelers.

Chapter 3 covers three studies carried out to understand the behaviour of the riders during crashes through in-depth PTW crash investigations, analysis of braking behaviour from naturalistic studies, and finally the current needs of the training instructors with a survey. The conclusions of Chapter 3 based on the three studies carried out represent the motivation of the skills selected (coupling perception and action), the selection of the traffic scenario and the requirements to implement the methods of the research.

Chapter 4 and 5 deal with the field experiments in a simulated 'pre-crash' scenario analyzing the perception and control skills of riders with different expertise. Chapter 4 also presents the theoretical optimum braking based on the geometry and characteristics of the instrumented scooter used in the tests. These two chapters cover the study of the performance analyzing response time and braking deceleration, establishing categories of skills based on objective parameters. Furthermore, a model able to predict the deceleration (i.e. braking distance) based on the braking patterns of the riders is presented. The model represents a more complete understanding of riders during braking manoeuvers, examining their behaviour to identify the key components necessary for effective interventions.

Chapter 6 outlines the tool defined to support instructors in the training of less skilled riders. The tool uses the model created from the braking profiles of expert riders to guide the training of less skilled riders to brake earlier and stop faster. The tool provides real-time visual feedback on a screen that shows the riders how their braking performance compares to the expert model. Simple graphics shows trainees how to improve their braking performance.

Finally in Chapter 7 the main conclusions of the thesis and recommendations for further work are presented.

The block diagram of the structure of this thesis is illustrated in Figure 1-5.

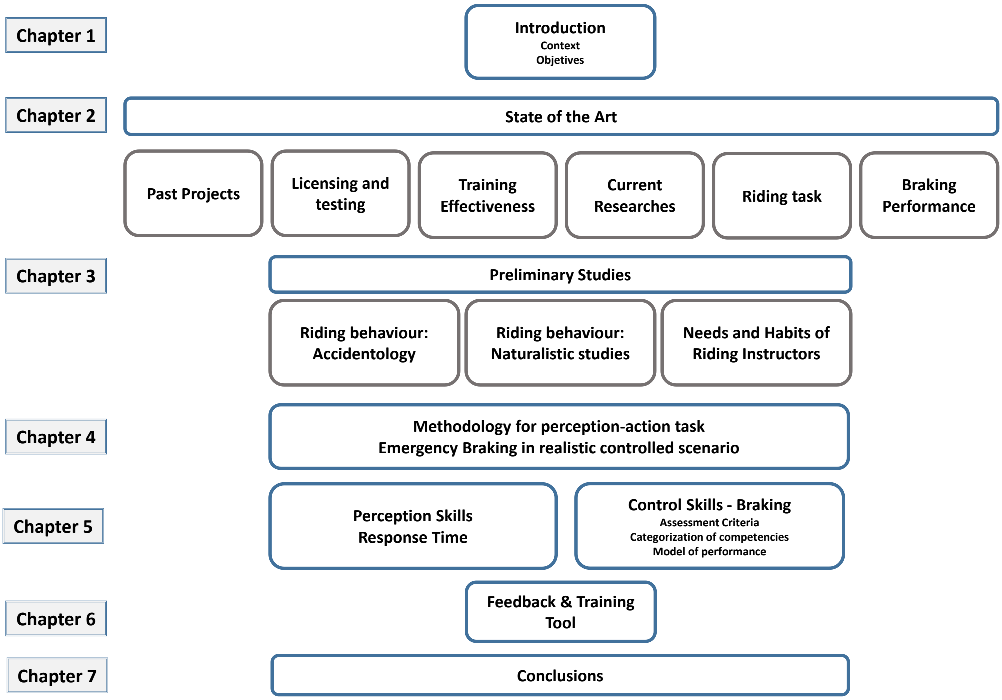


Figure 1-5. Block diagram of the study

2. State of the Art

2.1. Past Projects

Previous work conducted within international projects, including studies of PTW safety considering human interaction with vehicle and road and studies about training to enhance safety, provides a good reference about rider behaviour and training approaches. The next list, that does not include national projects focusing on riders training, present the previous international projects in chronological order in the following:

PROMISING (1998-2001): The PROMISING - Promotion of mobility and safety of vulnerable road users (pedestrians, cyclists, motorised two-wheelers) and young car drivers. The project aimed at developing measures that reduce the risk in a non-restrictive way.

ADVANCED Project (2002): Description and Analysis of Post-licence Driver and Rider Training. ADVANCED suggested a 'Good Practice' Framework concerning Topic Area, Objectives and Requirements.

MAIDS (1999-2004): MAIDS - Motorcycle Accidents In-Depth Study - This case control study analysed more than 900 motorcycle and moped accidents during the period 1999-2003 in five sampling areas located in France, Germany, Netherlands, Spain and Italy. To provide comparative information, more than 900 control cases have also been analysed in the same sampling areas.

ROSE-25 (2003-2005): The project ROSE-25 (Inventory and Compiling of a Europe Good Practice Guide on Road Safety Education targeted at Young People) investigated the situation of ROad Safety Education (RSE) in EU 25. The project involved 21 partners.

IRT: Initial Rider Training (2004-2007): This is one of the projects most related with training goals, since it gives keys to develop a standard of rider training that took the main points according to the view of the main stakeholders. Initial Rider Trainer (IRT) defined 3 complementary vertical modules of Theory, Machine Control and Traffic Interface, and one horizontal module of e-Coaching. The different modules and the program defined has been a reference for the new directive 3DLD. Besides this project remarked the need for a Europe-wide standard for IRT.

TRACE project (2006-2008): The objective of TRACE project (TRaffic Accident Causation in Europe) was to provide an overview of the road accident causation issues in Europe (including all kind of vehicles), and possibly overseas, based on the analysis of any current available databases.

TRAIN-ALL (2006-2009): TRAIN-ALL (Integrated System for driver TRaining and Assessment using Interactive education tools and New training curricula for ALL modes of road transport) aimed to develop a computer-based training system for the training and assessment of different land-based driver cohorts (motorcycle riders, novices, emergency drivers and truck drivers) that integrates multimedia software, driving simulator, virtual driving simulator and on-board vehicle sensors.

PISA (2006-2010): The aim of the PISA project was to develop and use new technologies to provide integrated safety systems for a range of powered two wheelers (PTWs).

SAFERIDER (2008-2010): SAFERIDER (Advanced Telematics for Enhancing the Safety and Comfort of Motorcycle Riders) was focused on the development and testing of innovative ARAS (Advanced Rider Assistance Systems) and OBIS (On-Bike Information Systems) for PTWs.

2BeSafe (2009-2011): The 2-Wheeler Behaviour and Safety project is the most important naturalistic riding study done in Europe so far, and aimed to study the normal behaviours of PTW riders in normal and emergency riding situations.

eSUM (2011): The European Safer Urban Motorcycling project aims at improving diagnosis of the urban PTW challenges, identifying and applying good practices in Urban Motorcycling Action Plans.

RIDERSCAN (2011-2014) - scanning tour for motorcycle safety – was a European project that dealt with the identification and comparison of national initiatives on PTWs, and the identification of best practices as well as critical gaps of the existing knowledge and critical needs for policy action.

SHRP2 NDS (USA) (2006-2015): The central goal of this Naturalistic Driving Study (NDS) from United States (that includes 100 Motorcyclists Naturalistic Study) was to address the role of driver performance and behaviour in traffic safety. The study pretended to track two age groups and seven motorcycle models and three different locations for outfitting, tracking, and data collection. Up to know only a few minor results have been published.

UDRIVE (2012- 2016): The eUropean naturalistic Driving and Riding for Infrastructure & Vehicle safety and Environment planned to include PTW data collection in Spain as part of different naturalistic studies. UDRIVE aimed to contribute to developing in-depth knowledge about crash causation factors and associated risks. Up to now there are no published results.

ABRAM (2013-2016): The ABRAM project aims to contribute to the safety issue associated to the use of motorcycles and mopeds by supporting the development of Motorcycle Autonomous Emergency Braking system.

The presented projects highlighted in different levels the importance of knowing rider’s behaviour or worked with training methods for safety. However, there is still a lack of knowledge to understand the behaviour and capacities of PTW riders in specific terms that support trainees to define solid targets and comprehensive feedback.

2.2. Licensing and testing to ride Powered Two Wheelers

One of the most important reference in the current approaches to driver education is the GDE matrix (Figure 2-1) defined in the EU project GADGET - Guarding Automobile Drivers through Guidance, Education and Technology -(Hatakka, Keskinen, Gregersen, & Glad, 1999). The application of this matrix to driver training was further discussed by Hatakka et al. (Hatakka et al., 2002).

Training content should be developed taking into account that crash risk is influenced by many factors, including ability to master the motorcycle, but also attitude and motivation regarding riding and safety.

Hierarchical level of behaviour (extent of generalisation):	**Central content of driver education:** Knowledge and skills the driver has to master	Risk increasing factors the driver must be aware of	Self-evaluation
Goals for life and skills for living (global)	**Knowledge about / control over** how general life goals and values, behavioural style, group norms etc. affect driving.	**Knowledge about / control over** risks connected with life goals and values, behavioural style, social pressure, substance abuse etc.	**Awareness of personal tendencies** re. impulse control, motives, lifestyle, values, etc. Developing self-evaluation skills.
Goals and context of driving (specific trip)	**Knowledge and skills** re. trip-related considerations (effect of goals, environment choice, effects of social pressure, evaluation of necessity, etc.).	**Knowledge and skills** re. risks connected with trip goals, driving state, social pressure, purpose of driving, etc.).	**Awareness of personal** planning skills, typical driving goals, driving motives, etc. Developing self-evaluation skills.
Mastery of traffic situations (specific situation)	**General knowledge and skills** re. rules, speed adjustment, safety margins, signalling, etc.	**Knowledge and skills** re. inappropriate speed, narrow safety margins, neglect of rules, difficult driving conditions, vulnerable road-users, etc.	**Awareness of personal** skills, driving style, hazard perception, etc. from the viewpoint of strengths and weaknesses. Developing self-evaluation skills.
Vehicle manoeuvring (specific task)	**Basic knowledge and skills** re. car control, vehicle properties, friction, etc.	**Knowledge and skills** re. risks connected with car control, vehicle properties, friction, etc.	**Awareness of personal** strengths and weaknesses re. basic driving skills and car control (especially in hazardous situations), etc. Developing self-evaluation skills.

Figure 2-1. Original GADGET matrix based on GDE framework. Source: Hatakka et al. 2002.

The theoretical based driver education model like the GDE-matrix has very significant contribution to the development of training of drivers of different modes of transport (Molina, García-Ros, & Keskinen, 2014; Peräaho, Keskinen, & Hatakka, 2003), mainly in EU with different funded projects (i.e., GADGET (Hatakka et al., 1999); ADVANCED (Bartl et al., 2002); MERIT (Bartl, Gregersen, & Sanders, 2005)). More recently, the Road User Education project of CIECA (Commission Internationale des Examens de Conduite Automobile) adapted the GDE Matrix for 20 different human factor failures in order to understand how the different levels are linked. Figure 2-2 shows the example of Hazard avoidance for safety car driving purposes that may be applied to PTWs (CIECA, 2015). In spite of the influence of this model in the theoretical conception of the training, the implementation of driver education system is still more focused on the operative and tactical aspects of driving with less significance to the strategic and personal levels of driving behaviour, as the work analyzing the drivers training curriculum in Spain revealed (Molina et al., 2014)

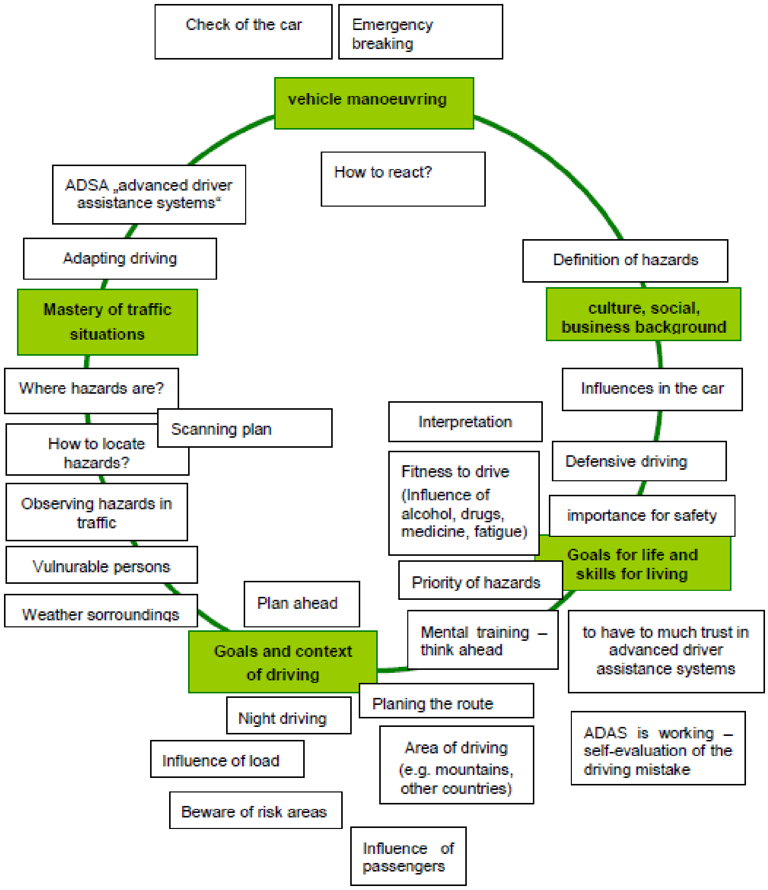


Figure 2-2. Application of the GDE Matrix for Hazard Avoidance. Source: CIECA, 2015

During the training program, in most countries the content concerning the theory test (traffic rules, mechanics, protective equipment…) is learnt normally by verbal instructions or self-studying in first place. Riding skills are procedural knowledge and must be learnt by practice, and in the first stage it is usually done initially in a parking lot and later on-road, in both cases supervised by an instructor or a high skilled rider that provides the feedback necessary to refine the learning. Current training focuses mainly on the first two levels of the matrix (operational and tactical). Trainees develop basic competences of control of the vehicle and knowledge of the rules very quickly, that in most cases is enough to pass their driving test in a short time. However, at this phase in most cases the riders/drivers lack of experience to develop complex cognitive and perceptive skills necessaries for safe riding performance (Groeger, 2002; Pereira & Santos, 2014). Higher order skills also take longer to be assimilated and, in addition, are critical to accurately perceive and respond to potential emergency scenarios.

Following similar criteria, and remarking the importance of a right intervention timing, Glad et al. (Glad et al. cited in Lund, 2006) defined the different steps of the driver training (Figure 2-3). This approach may be a good reference, however it did not include hazard participation as a specific subject.

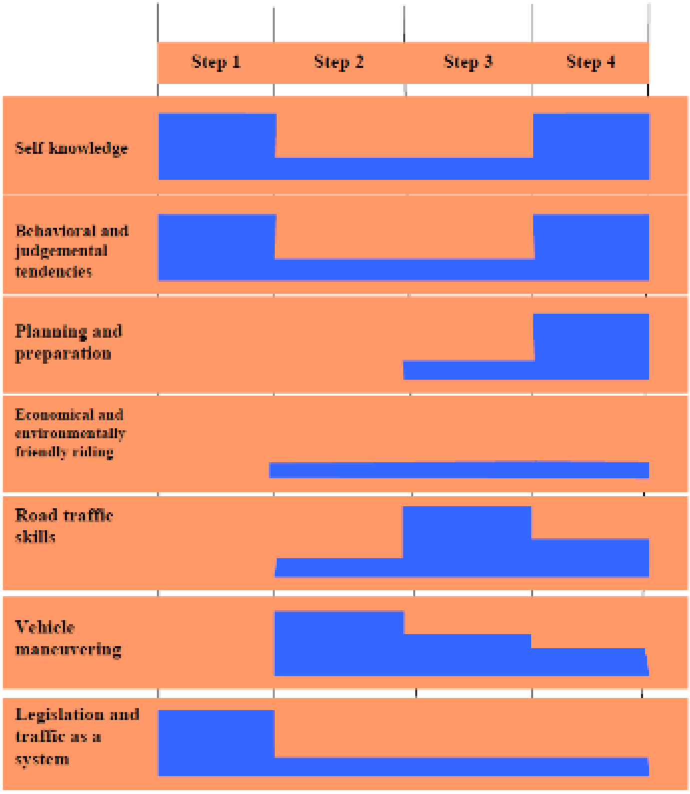


Figure 2-3. Relative scope of training within the various subjects and the division of the training into steps. (Glad et al. 2002 cited in Lund 2006)

2.2.1. Examples of testing and assessment

European Union: Current Legislation

Most European countries are subject to the EU Driving Licence Directive, and follow the requirements for licensing and testing according to Directive 2006/126/EC, which was implemented in 2013. The 3DLD provides four Motorcycle Licence Categories, each permitting the use of PTWs specific engine size and progressive power. Table 2-1 can be used as a highlight of the license system for the European States Members. Member States may raise or lower the minimum age for issuing a driving license. Member States may also give access to AM (moped) or A1 (Light Motorcycle) PTW classes for people with a full car licence. This equivalence would be applied only on their territory.

Table 2-1. Riding Licence in Europe - age and engine power restrictions within the 3rd Driving Licence Directive/ Overview of the current licensing system

Item	***3rd Directive***	
	Restrictions	Conditions
Category AM (moped)		
Maximum Speed (km/h)	45	Theory test
Maximum engine power (kW)	4kW	Practical test is optional of the Country (f.i. in UK you must pass a moped practical test to obtain your full moped licence)
Maximum capacity (cm^3)	50 cm^3	
Minimum age	16 (subsidiary 14 to 18)	
Category A1		
Maximum engine power (kW)	11kW	Theory and practical test
Maximum capacity (cm^3)	125cm^3	
Maximum power weight (kW/kg)	0.10	
Minimum age	16 to 18 (subsidiary)	
Category A2		
Maximum engine power (kW)	35kW	Theory and practical test
Maximum power weight (kW/kg)	0.20	If holder category A1 for 2 years, passing a test or complete a training only
Minimum age	18, but min A1 age +2 years	
Category A		
Maximum engine power (kW)	(including above 35kW)	(20 years for progressive access) Passing a test or complete a training
Maximum capacity (cm^3)	-	
Minimum age	24 but min A2 age + 2 years	(24 years for direct access) Theory and practical test

The Directive has detailed requirements relating to the theoretical test, special manoeuvres test and the on-road testing.

Theory Test. There are two different contents for the theory: the main part is the content concerning all vehicle categories, and the other part is specific concerning motorcycles. Questions must be asked on each of the points listed below, the content and form of the questions being left to the discretion of each Member State:

All vehicle categories:

- Road traffic regulations
- The driver
- The road
- Other road users
- General rules and regulations and other matters
- Precautions necessary when alighting from the vehicle
- Mechanical aspects with a bearing on road safety
- Vehicle safety equipment
- Rules regarding vehicle use in relation to the environment

Motorcycle knowledge on:

- Use of protective outfit such as gloves, boots, clothes and safety helmet;
- Visibility of motorcycle riders for other road users;
- Risk factors related to various road conditions as laid down above with additional attention to slippery parts such as drain covers, road markings such as lines and arrows, tram rails;
- Mechanical aspects with a bearing on road safety as laid down above with additional attention to the emergency stop switch, the oil levels and the chain

Practical Test (Skills and Behaviour). The characteristics are the following:

- *Marking of the test of skills and behaviour*:
  Based on the expert criteria of the inspector by observation. The assessment of the degree of ease with which the applicant handles the vehicle controls and his demonstrated capacity to drive in traffic in complete safety and the defensive and social driving behaviour showed.
- *Length of the test*:
  In no circumstances should the time spent driving on the road be less than 25 minutes.
- *Location of the test*:
  - Assessment of the special manoeuvres may be conducted on a special testing ground.
  - Assessment of behaviour in traffic should be conducted on roads outside built-up areas, expressways and motorways (or similar), as well as on all kinds of urban streets (residential areas, 30 and 50 km/h areas, urban expressways) which should represent the various types of difficulty likely to be encountered by drivers.

Riderscan project (Delhaye & Marot, 2015b), which dealt with different stakeholders that assessed the 3DLD, recommended to give priority to the harmonizing training by implementing a common framework along with the definition of minimum standards that avoid differences in the compulsory license. On the other hand, not only do differences in the compulsory license exist in Europe, but also significant disparities in terms of riders' safety. While the difference in overall road safety performance between the worst and the best performing European country is a factor of 3, the difference for PTW riders is a factor of 30 between the best performing (Norway) and the worst (Romania) (Figure 2-4; ETSC, 2011).

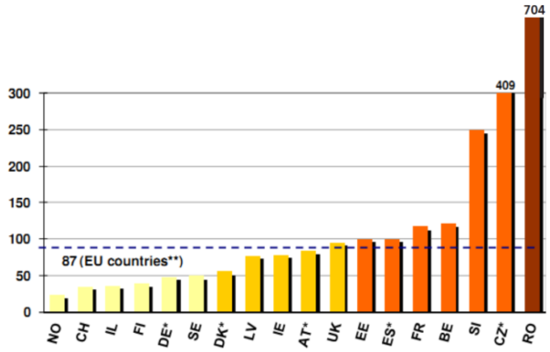


Figure 2-4. PTW rider deaths per billion kilometers ridden in 2009. Source: (ETSC 2011).
***AT, DE (2008); CZ, DK, ES (2006). BE, UK: Mopeds not included. **Average for the EU Member States.**

Although this data is a good reference, it is important to note that factors like road network characteristics, the type of usage of the PTW (leisure, commuting...), the type of PTW most frequent or the riders' equipment must be taken into account for an complete assessment of the road safety performance of the riders by country.

USA (NHTSA standards)

Concerning the National Highway Traffic Safety Administration USA, in 2011 they published the standards to serve as a model for all novice motorcycle rider training programs conducted in the United States and to establish baseline content that all riders should be taught in such entry-level classes (NHTSA 2011). This model represents a good reference about training programs. The model sets tasks sequentially from simple to complex. In order to meet the model standards, all tasks identified in this standard must be included in the developer's curriculum design and material.

The model standards defined by NHTSA are grouped into the following six sections:

1.	Motorcycle Pre-Ride Tasks
2.	Vehicle Control Skills
3.	Street Strategies: The rider…
a)	understands hazards associated with riding.
b)	searches the roadway environment to anticipate and identify hazards.
c)	understands strategies to avoid hazards.
d)	understands how to respond correctly to hazards.
4.	Roadway Management Skills: The rider understands…
a)	proper technique for slowing quickly and stopping in the shortest distance in a straight line.
b)	proper entry speed and path of travel when cornering a motorcycle.
c)	proper techniques for slowing or stopping quickly in a curve.
d)	proper techniques for swerving to avoid a collision.
e)	proper techniques for making lane changes and/or passing other vehicles.
f)	how to adjust to surface hazards and roadway conditions with reduced traction.
g)	how to ride in conditions of limited visibility.
h)	proper techniques for riding at night.
i)	proper techniques for riding in the rain.
j)	how to adjust to windy conditions.

5.	Tasks Related to Carrying Passengers, Cargo, Group Riding, and Touring
6.	Factors Adversely Affecting Rider Performance

Australia

In the state of Victoria, Vic Roads proposes four learning stages with practice tasks associated to 4 main topics. The main topics *move*, *lean* and *stop* are linked to control skills and the topic *protect* is a mix of higher order skills composed by hazard perception, traffic strategy and behaviour.

Stage 1 Practice Tasks Learning the basics	Stage 2 Practice Tasks Coping with cars and corners	Stage 3 Practice Tasks Handling the wide open road	Stage 4 Practice Task Continuing to improve
Move Get used to throttle and gears Pull out, pull in	**Move** Program in the feel of tracking a bike straight Slow riding and scanning Stop and go with feet up Change gears up and down many times Change down two gears and maintain speed Quick checks to test your attention	**Move** On the foot pegs Riding over obstacles	**Move** Improve gear changing Smooth enough for pillion' Manoeuvre with pillion
Lean Weaves Simulate turns Ride out of driveway Pull out and go in opposite direction	**Lean** Tight turns Walk a U-turn Ride a U-turn Weave faster Head and eyes for turns	**Lean** Swerve or quick lane change Go, stop, turn	**Lean** Winding roads Leaning with pillion
Stop Set up and squeeze Look ahead and stop in a straight line Check mirrors and stop in a straight line	**Stop** Brake in a straight line	**Stop** Quick stop, straight Brake into a curve	**Stop** Brake in a curve Brake and gear together
Protect Check your tyre pressures Looking up Able to look around? Head checks	**Protect** How soon do you respond to dangers? Can you stop for unexpected hazards? Move away from threats Stay away from threats in curves Respecting your brain's speed limit	**Protect** Recognise your own carelessness Balance safety against fun Ride on the edge or to stay safe?	**Protect** Risk check

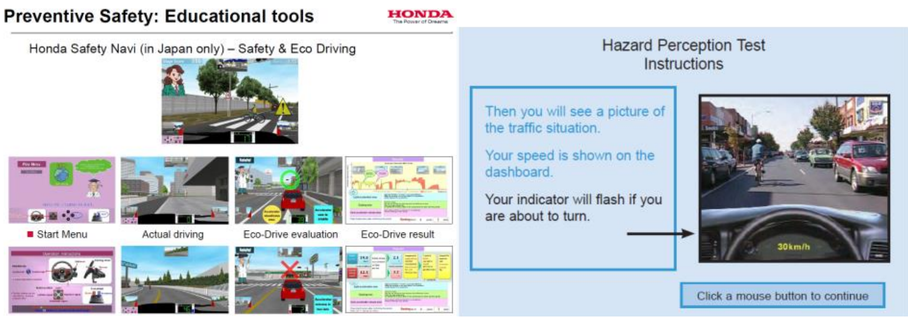
Figure 2-5. Example of the practice tasks associated to learning stages proposed by Vic Roads (Australia). Source: https://www.vicroads.vic.gov.au

Conclusion

The provision of initial rider training that is needed to obtain the necessary knowledge and skills to ride a PTW and gain a *PTW riding* license, varies broadly depending on the countries including EU Member States. Such training can be either freely accessible on a voluntary basis, or mandatory prior to passing the test of the driving license. The requirements and content of such training in the EU are based on the European directive, but they are not legislated by the EU since it is a national competence and responsibility. As consequence, there is noticeable diversity among the requirements of the different countries (from the very extensive and expensive to virtually non-existent). Not harmonized training makes that training effectiveness is not possible to assess in an overall concept, since among other factors it will depend mainly on the kind of training. It is important to take into account that once the programs show positive or negative effects, the relevance to other countries/states will depend on the degree of similarity in regulatory, economic and cultural environments (Blackman and Haworth 2013).

2.2.2. **Hazard Perception Courses**

Inclusive training in hazard perception and in managing hazards is rarely included actively in the curriculum of the current courses. Although no program specific to hazard perception for motorcycle riders has been developed (Haworth et al. 2005) in some countries like the U.K. or Australia applicants for motorcycle license must pass a computer-based hazard perception test. In Australia, training in hazard perception and control started more than a decade ago (Figure 2-6a), with a recommendation that such a program should combine class, simulation, and on-the road training. However an evaluation of such an operational program has still not been performed and currently the computer-based Hazard Perception Test (HPT) is one of the requirements needed to get the riding license. It is important to remark, that this test was designed for car drivers with different risks and behaviour. For instance, risk factor for a PTW such as unclean road and loose material on the road, which can contribute significantly to the occurrence of a PTW crash, are normally not considered as causation of car crashes. These differences emphasize the added mental effort and attention that motorcycle riders must allocate to the road ahead of them (Narelle Haworth 1997).



a) **b)**

Figure 2-6. a) Hazard Training from Honda in Japan. Source: Honda; b) HPT from Australia. Source: Government of Western Australia Department of Transport

In Japan, training in a basic static simulator with multimedia tools and little physical fidelity is part of the requirements for motorcycle licensing (Haworth et al. 2005) (Figure 2-6), but the benefits of this approach are still unproven.

More recently, in Netherland the advanced rider training course '*Risk'* includes hazard perception training with multimedia application that has resulted effective according to hazard perception tests (Boele-Vos and De Craen 2015).

Although these examples of hazard perception tests deal with hazard detection training, most of the training and tests of hazard perception focus on the hazard detection aspect and ignore the response aspect (Shinar, 2007), since many of the approaches require only detection of the hazard and response by pressing a button in front of a computer. Haworth et al. (2005)

concluded in their review of hazard perception tests that not attention has been directed to training riders on how to respond to hazards and dangerous situations.

2.3. Training Effectiveness

The validity of the training programs remains questionable after reviewing the literature. There is no consensus on the positive effect of training in view of the previous researches that studied the relationship between rider training and reduction of crash and their severity. The two most complete reviews that analysed the validity of the previous studies in detail are by Daniello et al. (Daniello et al., 2009) with a review of existing research on the effectiveness of motorcycle education courses and different licensing procedures, and the Cochrane review by Kardamanidis et al. (Kardamanidis et al., 2010). Also interesting are the reviews of motorcycle training's effectiveness done by Elliot et al. (Elliott et al., 2003; Sexton & Elliott, 2009), with similar results. All the reviews showed high discrepancies among the studies, including the methodologies conducted. The literature shows studies that reported that motorcycle riders with training had fewer accidents per person than untrained riders (Baldi, Baer, & Cook, 2005; Davis, 1997), studies that found no differences in accident rates (Jonah, Dawson, & Bragg, 1982; Rudolf G. Mortimer, 1988), and even studies that found higher accident rates with trained riders (Savolainen & Mannering, 2007). Billheimer (1998) demonstrated that in the first 6 months following training, riders with little experience before training tended to have fewer accidents than untrained riders with a similar amount of experience. However, after this time period, there was little difference in the accident rates.

One of the most interesting results from the recent studies and more representative of the effect of the methodology in the results is the study conducted in Spain by Perez et al. (Pérez et al., 2009). This work assessed the effect of the law from 2004 that allowed car drivers holding a car driving license for more than three years to ride light motorcycles ($\leq$ 125cm^3) without any test or PTW license. The study, that used data from 2002 to 2008, stated as first conclusion that allowing car drivers to ride motorcycles without passing a special test increases the number of road injuries from motorcycle accidents. However, when the exposure was taken into account adjusting the results per number of registered PTWs, the difference was not significant for the number of injuries on light motorcycles (Odd Ratio 1.03; CI 95%: 0.80–1.34).

The conclusions about the past studies is that they present important methodological limitations that in most cases lead to inconclusive results and in others cast doubts on the reliability of the results. In summary, the most common shortcomings found are the following:

- Methodological weakness, in many cases omitting the adjustment of relevant control variables and working with poor control groups. The results of these previous studies may be more affected by the methods used to evaluate motorcycle training than the effectiveness of training itself.
- Small sample sizes.
- Questionable self-reported data that in addition cannot include fatal and most severe injuries.

Moreover, the inconsistency across training programs makes difficult to compare the results from different studies. Different studies present different curricula and different motivators for receiving training among the studies. The study sponsored by the NHTSA (Brock, Robinson, Robinson, & Percer, 2010) with an expert panel of motorcycle safety researchers and training specialists evaluated the effectiveness of entry-level rider training on reducing motorcycle crashes. The panel determined that methodologically strong study should consider: consistency across training programs, self-selection bias, population, demographics, adequate sample size, and controlling level of exposure during study (Brock et al., 2010).

The fact that several studies have reported that rider training is not effective in terms of safety, does not necessarily point to the inefficacy of training to increase safety, but the need for more effective program design. There are different possible reasons. In a review of motorcycle training's effectiveness, Elliot et al. (Elliott et al., 2003) highlighted key aspects that could be understood as possible reasons. The reasons summarized are the following:

- Skills are not being learned by the riders / Rider are not learning the skills taught
- Skills are not being translated into on-road riding
- Skills related to crash involvement are not clearly identified and not properly trained
- Inappropriate design or content of training
- Inherent limitations in what training alone can achieve. (More customized approach)
- Fail to recognise different training needs. Different rider profiles need to train more intensely different skills

2.4. Limitations of the current researches on educational and licensing systems

Different researches have studied the rider education and licensing systems (Aupetit et al., 2013; Baldi et al., 2005; Haworth et al., 2012; Haworth & Mulvihill, 2005; Reeder, Chalmers, & Langley, 1995). The European Project IRT (IRT, 2007) commented in section 2.1 also gave some keys concerning the training system in European Union. Probably the most in-depth study concerning the content of a riding course was the one by Aupetit et al. (2013) in France. This section summarizes the main conclusions from the literature reviewed:

- Marked disparities between the situations encountered during the training and after the test in the real traffic. Riding test situations are used for track and on-road training situations. The training systems tend more to prepare the motorcyclists for the final exam than to teach them how to ride in the real traffic (Aupetit et al., 2013; Haworth & Mulvihill, 2005). The review of Wallace et al. about hazard perception training (Wallace, Haworth, & Regan, 2005) indicates that during formal training in a harm-free environment the hazardous conditions actually presented are very restricted. Trainees need real-world conditions to become fully skilled riders. There is a need to find ways of ensuring that training has a broader focus.
- There are no objective definitions of basic and proficient skills (Brock et al., 2010; Sexton & Elliott, 2009). The *basis for skill assessment* are indicators based on the observation of the rider performance (Wallace et al., 2005). There is a lack of new technology implemented to improve the learning process. Instrumented vehicles are key tools for in-depth understanding of rider's behaviour (Espié, Boubezoul, Aupetit, & Bouaziz, 2013).

- Training is focused on the control of the motorcycle to the detriment of the perceptive and cognitive dimensions required for riding after the test (Aupetit et al., 2013; Sandroni & Squintani, 2004). Training should not focus only on improving control riding skills, it should also make riders aware that they cannot rely on their own skills in handling a critical situation. The aim of such training should be to calibrate the driver's self-assessment and to encourage riding with larger safety margins (Sandroni & Squintani, 2004).
- Little importance is given to the teaching of perceptual skills which nevertheless play an important role in road traffic accidents involving motorcyclists (Aupetit et al., 2013).
- Research suggests that both basic skills and higher-level behavioural and motivational aspects of motorcycling need to be improved (Sexton & Elliott, 2009).
- Not enough hours on track/road. There is a common thought that increasing the number of hours will make the training too expensive (and thus less competitive if other riding schools offer cheaper prices) and it is not necessary if you already drive a car. This is a critical factor, balancing the need of an affordable training that does not restrict the access to PTW users with the need of repeated procedural training for the acquisition of expertise (Ericsson, 1998, 2004; Ericsson, Krampe, & Tesch-Romer, 1993)
- Repetition as the only strategy. One option suggested by Aupetit et al. (2013) is limiting the number of repetitions in order to release time to teach other skills (e.g. hazard perception skills) while maintaining the same duration of training.
- Time limitations in the acquisition of riding skills and lack of research examining perceptual-motor anticipation in the setting of driving or riding.
- Advanced control skills contents may favour the development of "overconfidence" (Elliott et al., 2003; Rowden & Watson, 2008), that is associated with risk behaviour.
- Courses should focus more on the specific needs of each participant and on how to encourage them to improve their driving style and behaviour. This can only be achieved through more participant-centred methods, designed to encourage participants to reflect on their strengths and weaknesses (self-reflection) and to provide the motivation to change. Only through an objective characterization of the competencies of the riders will it be possible to know the specific needs of the trainees and consequently define a training based on rider-centred methods.
- Motorcycle trainers vary in their teaching skills and in the way that they deliver the same curriculum (Haworth, Smith, & Kowadlo, 2000). Thus, it is needed quality assurance either by training organisation or the regulator (or both). There is insufficient evidence to assess whether specific training qualifications are helpful.

The RIDERSCAN project (Delhaye & Marot, 2015a) acknowledged three general research needs concerning rider training: a) identify skills to be learned to enhance safe riding; b) define the methods to learn/train these skills efficiently at driving schools; c) validate the two first needs identifying how the skills learned actually influence riding in real traffic situations.

2.5. Riding task

Driving task was defined by Hollnagel & Woods (2005) as an evolution of the classical driver-car system where the environment (roads, road users and climate conditions) should be considered as key factor. The system may be applied for PTW riding task, with the difference of the extra complexity of stability, conspicuity and vulnerability associated. The riding task is a PTW-rider-road system where the rider must interact processing the information of the riding scene and applying control measures continually with vehicle and environment. In emergency situations, the limit normally is not in the difficulty to process the information but in the reduced time available to make the right decision at the appropriate time and execute the right actions with enough accuracy to avoid the collision or the fall. Thus, training cannot focus independently in tasks related to the control of the vehicle or the perception awareness, training needs to couple the intrinsic action-perception task of riding. Figure 2-7 shows the simplest possible representation of each system as input, processing, and output functions.

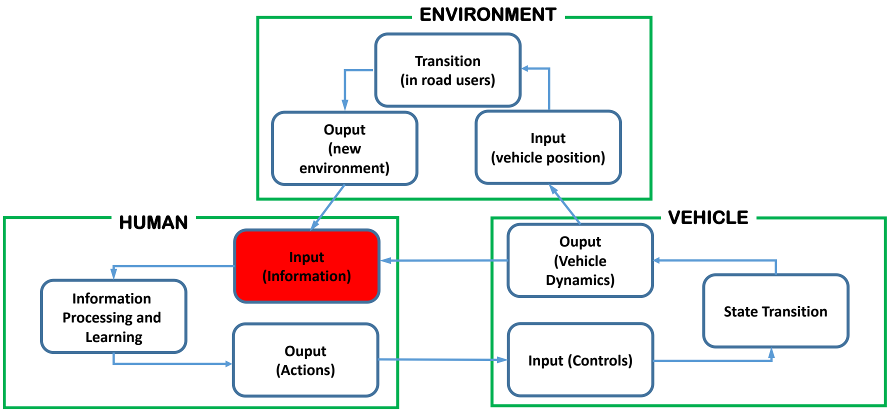


Figure 2-7. PTW-rider-environment system to present input/output exchange in riding scenario. Source: Adapted from the adaptation of Broughton (2007) from Hollnagel & Woods (2005)

The four components model of responding to risk proposed by Grayson et al. (2003) is considered as one of the most appropriate framework for motorcycle rider's hazard anticipation. The four components of this framework are:

- Hazard Detection (detection + diagnosis)– being aware that a hazard may be present
- Threat Appraisal (prognosis)– evaluating whether the hazard is sufficiently important to merit a response
- Action Selection (decision) – having to select a response from one's repertoire of skills
- Implementation (action) – performing the necessary actions involved in the response that has been selected.

Response implementation is more crucial for motorcyclists than for car drivers, as riding a motorcycle requires more complex manoeuvring skills than car driving. In emergency scenarios, the limited time to react with an evasive manoeuver may inhibit the action selection component from this model, resulting in freezing the possible action by panic or reacting with automatisms acquired.

Analogous to the four components model of Grayson, the TRACE project (Van Elslande, Naing, & Engel, 2008) described a classification model for human functional failures in road accidents that follows a sequential information processing chain of human functions in information gathering, processing, decision and action. Due to the complexity of the driving task and the permanent adjustments needed, the chain is not a strictly a sequential process but there are feedbacks among the categories.

The classification model distinguished six types of failures: failures at the information detection stage, at the diagnostic stage, at the prognostic stage, at the decision stage on the execution of a specific manoeuvre, at the psychomotor stage of taking action, and overall failures affected by the psycho-physiological competencies of the driver. Based on in-depth data collected on accident scenes of cars the project defined 20 cases of human functional failures covering each category (Figure 2-8) that may be applied to other road users as PTW riders to give a view of the complexity of riding in a traffic system.

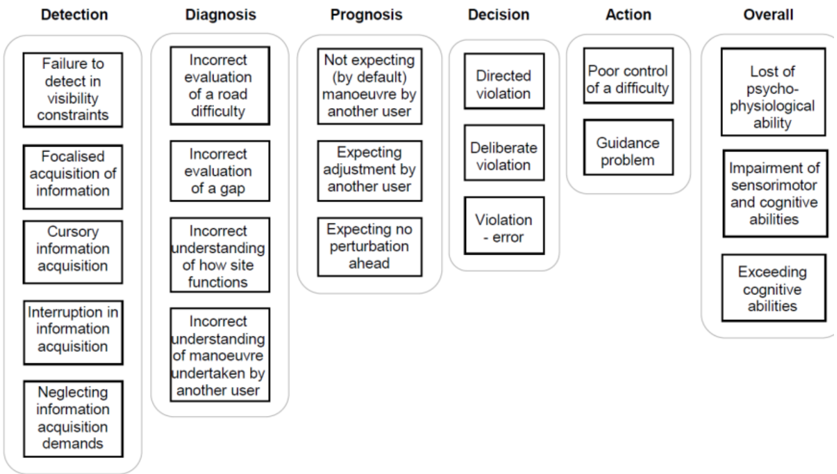


Figure 2-8. Global stages of human malfunction chain potentially involved in accidents. Source: (Van Elslande et al., 2008)

Although different models present similar components of responding to risk or stages of the human functional failures, it is important to set a general model with a common taxonomy to facilitate an efficient analysis of the human behaviour and avoid the misunderstanding of the results. This is particularly important for the in-depth studies of accident cases. The failure classification of the in-depth studies, that use observations and interviews, may be unsuccessful if the model is not well defined. On the other hand, different in-depth studies with different models make not possible to identify or compare the most relevant lack of skills related to safety using different literature. A clear example of this is the MAIDS study. MAIDS study defined four categories of primary contributing human factor failures assigning different terminology to similar concepts. For example, to refer to information detection failure is used the term *Perception failure* that is defined in the study as *fail to detect the dangerous condition based upon the strategy that he was using to detect dangerous conditions*. From the other three categories, *Comprehension*, *Decision* and *Reaction failure*, only *Decision* seems common in name and concept to the models previously defined in this section.

2.6. Skills to train: Control/Perception/Behaviour.

This section presents the skills needed related to emergency scenarios classified in the following topics[1]:

- Control Skills- Emergency Manoeuvres
- Hazard Awareness: Including stages detection, diagnosis, prognosis
- Rider Behaviour: categories of behaviour, self-assessment and overconfidence issue

2.6.1. Control Skills – Emergency Manoeuvres

Control skills are considered at the lowest level of the hierarchical system of decision (Janssen, 1979). Although these skills often are not critical for the safety, control skills are crucial in the collision avoidance during emergency scenarios. The vehicle control skills involved in riding a motorcycle are more complex than driving a car and failure to correctly implement a response to a hazard may in itself be dangerous (Wallace et al., 2005). Braking a PTW is key for avoiding accidents, but it is one of the most difficult tasks. Errors in braking can easily lead to skidding, capsizing or the PTW becoming unstable. At the same time the motorcycle rider has to maintain stability, to prevent the wheels from locking and sliding, to provide the shortest possible stopping distance in combination with the highest possible deceleration, and apply an ideal ratio of front to rear brake force distribution by normal separated brake systems.

Besides, the rider has to carefully apply braking force taking account of the quality of the road surface and the leaning angle of the PTW. As a result during emergency braking riders often apply a weak brake or lose control locking the wheels (SafetyNet, 2009). Concerning in-depth crash data studies, braking is also the most frequent emergency manoeuvre (ACEM, 2009). Penumaka et al. (2014) concluded that hard braking (i.e. close to wheel locking) was more common in experienced riders and weak braking (i.e. sub-optimal braking) was more common in novice riders. Similar conclusions produced the study in UK (ROSPA, 2006) that reported that incorrect use of motorcycle brakes is considered a factor in many crashes.

Although new technologies seem to promise shorter stopping distances and overall safer stopping for motorcyclists, assuring that motorcyclists get maximum braking performance requires additional training and education on proper braking and panic-braking techniques (Huang & Preston, 2004). Greater emphasis during training on how to brake correctly may help new riders, and also experienced riders without the competencies for these emergency scenarios. In the last case, objective indicators of performance are even more important, since it may prove more difficult to persuade riders to brake in the way that the training advocates (Sheppard, Hester, Gatfield, & Martin, 1985).

[1] More information about this topic may be found in deliverable D1.1 of Motorist project (Huertas-Leyva, Kovácsová, & DiGesu, et al. 2015).

Lastly, it is important that control skills training does not mislead the riding task pushing the riders to perform evasive manoeuvers instead of encourage a defensive riding (Hatakka et al., 2002).

2.6.2.Hazard Awareness

Hazard perception and responding is critical for riders since they cannot rely on other road users seeing them and because the severity of the consequences of failures are high as vulnerable road users riders (Narelle Haworth, Mulvihill, & Symmons, 2015). One of the key conclusions of the IRT project is that hazard awareness and perception are inadequately integrated in the existing training offer pointing the need to balance machine control with hazard awareness and social responsibility in IRT.

Motorcyclists need to scan more frequently the road surface because as a potential source of hazards. This fact, together with the need to scan intermediate and distant environment increases the work load of information processing (Nagayama, Morita, Miura, Watanabem, & Murakami, 1980).

Crash statistics showed that traffic scenarios like intersections, roundabouts, change of line, or traffic lights can increase the likelihood of failure to give right of way to the PTW, rising the risk of collisions (ACEM, 2009; Hurt et al., 1981; Lynam, Broughton, Minton, & Tunbridge, 2001). "*A good rule of thumb for safe riding is that in interacting with cars and trucks it is much better for the motorcyclist to be safe than right"* (Shinar, 2007:676).

The necessity to control the PTW balance, its lower friction capacity and its greater sensibility to environmental perturbations means added mental effort and attention that motorcycle riders must allocate to the road ahead of them. In order to avoid accidents, motorcyclists must develop the ability to detect, assess, and deal with such potential hazards. Hazard awareness including hazard perception and decision (quick appropriate responses to emerging hazards) are the main skill that riders must acquire. To appropriately respond to an unexpected hazard a rider has to disrupt a mostly automatic process of riding, in order to perceive and assess an infrequent or rare event and then respond to it in a controlled (rather than automatic) and less practiced manner (Shinar, 2007).

The model of risk perception of Grayson et al. (2003) and the SEE strategy (search/evaluate/execute) defined by Ochs & Buche (2010) are good reference where the training can be based on. Concerning the training strategy, three categories of scenarios should be used to evaluate scanning and vehicle management as hazard anticipation skills.

- scenarios where the threat is visible, but latent (e.g., cars in the left of two travel lanes waiting to turn left).
- scenarios where a threat is obscured by an object (truck, building, bush) in the environment. In order for a driver to anticipate the hidden threat, it must be cued in advance, such cues including pavement markings, signs, or the geometry and placement of objects in a given environment.
- scenarios where the threat is on the road (oil, holes, wet road with low friction…)

Each of these categories involves different visual cues. The first is probably the most elemental and easier to reproduce in a real-world controlled scenario. The second involves disguise of the first whereas the third involves environmental or situational variables of physical context.

2.6.3. Rider Behaviour

Whereas riding control skills may be expected to improve with training and experience, driving style becomes established over a long period of time and is governed by lifestyle, personality factors, attitudes, and beliefs which are overall hard to change (Elander, West, & French, 1993; Lajunen & Özkan, 2011).

Categories to classify riding behaviour

Elliott, Baughan, & Sexton (2007) administered a Motorcycle Rider Behaviour Questionnaire (MRBQ) among British motorcyclists and proposed five categories of motorcyclist behaviour: traffic errors, control errors, speed violations, performance of stunts, and use of safety equipment. The five-factor solution of the MRBQ was also replicated among Turkish riders (Özkan, Lajunen, Dogruyol, Yildirim, & Çoymak, 2012). Similar approach was followed in Australia with a four-factor solution merging traffic and control errors (Sakashita et al., 2014).

Overconfidence

Some steps will have to be taken in order to avoid the training in riding techniques being run in such a way that turns out in an unrealistic picture of the rider's abilities. Tests where rider can have an objective evaluation of his performance can help to have a more realistic self-assessment, besides they will reduce overconfidence that may address to risk taking behaviour. It is important for participants to recognise their own personal limits, whether psychological or in terms of individual ability. In this respect, experiencing and recognising one's own personal limits is at least as significant as experiencing physical limits (Boele-Vos & De Craen, 2015).

Another method to complement the test track training based in Lund for the training curriculum in Norway (Lund, 2006) is meeting the trainees in group before and after the course of advanced control skills aiming to assure that the learners will not misuse their acquired abilities to increase the general risk levels in traffic following the recommendations of. A good outline of how to address overconfidence was defined during the EU *Advanced* project (Bartl et al., 2002). The methods included:

- Demonstrating certain risk awareness exercises (followed by discussion), instead of allowing participants to drive, thus incurring the risk of the participants interpreting the exercise as skills-based.
- Making sure that participants "fail" (e.g. hit obstacles, lose full or temporary control of the vehicle, experience fear/shock) during skills-based exercises (experiencing limits)
- practical exercises followed up with sufficient participant-centred discussion, designed to consolidate on the intended message of the exercises.

2.7. Literature about Braking Performance

The previous sections have remarked the importance of driving style, hazard perception to predict risk and increase the time to react, and control skills when facing imminent collision (mainly braking) for motorcyclists because of the intrinsic instability of a PTW. In addition, it has been stated the critical significance of perceptual skills including hazard detection, threat appraisal and decision, concluding that effective training needs to couple the intrinsic action-perception task of riding. This section presents the works that have studied the braking performance of riders putting more attention on the few studies that have tried to integrate the action-perception task.

As it has already commented in this thesis, braking is considered one of the most complex task of riding (Sheppard et al., 1985) and it is critical in an emergency situation. In addition accident data analysis has shown that in those accidents where the rider had to brake to avoid collision, riders often did not perform correctly (Hurt et al., 1981; Penumaka et al., 2014). Cossalter et al. (Cossalter, Lot, & Maggio, 2004) defined “optimal” braking as the manoeuvre where the front and rear wheels achieve the same braking force coefficient, but the correct braking style should also change as the adherence conditions change. Moreover, a correct braking balance may significantly improve vehicle stability.

Previous studies with PTWs have defined the theoretical optimum braking maneuver (Corno, Savaresi, Tanelli, & Fabbri, 2008; Cossalter et al., 2004), measured braking performance of riders (Davoodi & Hamid, 2013; Ecker, Wassermann, Hauer, Ruspekhofer, & Grill, 2001; Prem, 1987; Vavryn & Winkelbauer, 2004) and assessed the potential benefits of motorcycle autonomous emergency braking (G. Savino, Giovannini, Baldanzini, Pierini, & Rizzi, 2013),
.

Mortimer (R G Mortimer, 1988) assessed the performance of motorcyclists in braking with separated and combined brake system (named “integrated braking systems”). During the experiment five experienced riders (not experts) had to attain a speed of 40.3 km/h (25 mph) and had to apply the brakes when they reached two cones as reference. The effective deceleration was calculated based on the stopping distance between the cones and the front wheel of the motorcycle, and assuming an initial speed of 40.3 km/h. The study revealed large increases in braking performance with combined brake system compared to conventional separated systems.

Vavryn & Winkelbauer (2004), with their experiment showed that experienced riders with motorcycle without ABS on average achieved a braking performance of about 6.6 m/s^2 and novices after six hours of training about 5.7 m/s^2. Experienced riders achieved 7.8 m/s^2 braking on a PTW with ABS and 6.6 m/s^2 riding their own vehicles. The starting speed was between 50 and 60 km/h. Gail et al. (Gail, Funke, & Seiniger, 2009) examined the safety potential of Anti-Lock Braking Systems (ABS) measuring stopping distances on nine riders who completed 105 braking manoeuvres each using different braking systems (ABS, CBS, conventional). They showed that riders achieve shorter braking distances with ABS than without.

More recently, Savino et al (2012) defined a method using HMIs and an instrumented PTW, to improve braking performance in a straight line. Also valuable is the research of Seiniger et al. (Seiniger, Schröter, & Gail, 2012) about stability and optimal brake force distribution during corner braking.

A few previous studies have also estimated the onset of braking by visually determining the timing of brake light illumination and measuring the distance with cameras (Davoodi, Hamid, Pazhouhanfar, & Muttart, 2012; Ecker, Wassermann, Ruspekhofer, Hauer, & Winkelbauer, 2001).

Kawakoshi et al. (Kawakoshi, Kobayashi, & Hasegawa, 2014) studied the performance of 19 riders (4 experts) conducting deceleration braking tests with an initial speed of 60km/h and three different target decelerations (2, 4 and 6m/s^2). A light braking signal at the end of the line informed the rider that had to brake immediately and stop just before a stopping line. The average response time of expert and ordinary riders was 0.32 and 0.38 seconds respectively without statistical analysis to know if the differences were significant. One shortcoming of the response time values was that during tests riders might not respond immediately in response to the signal because they had a margin in the distance to the target stopping point. No remarkable differences were found between experts and ordinary riders in the effective decelerations since the target was to brake at a maximum deceleration of 6m/s^2 excepting two ordinary riders that couldn't reach the 6m/s^2 deceleration.

In most of the previous studies, deceleration rate was determined indirectly from measures of distance. This method yields only values for effective deceleration, instead of using instantaneous deceleration with high frequency rate to understand the actions of the riders during the whole braking period. Anderson & Baxter (Anderson & Baxter, 2010) measured the constant higher deceleration values for PTWs with different braking systems but the values were collected only from one expert rider and the only measure of speed was done with a laser rather than directly determining wheel speed and longitudinal acceleration.

The past studies have helped to know the performance of different braking systems, PTW types and in a few cases type of riders in terms of effective deceleration. Nevertheless, there are no existing studies that have used the dynamic measurements of the motorcycle in a realistic hazard scenario to assess rider skills. There are still no studies that understand and characterize with objective indicators how the rider actually interacts with the vehicle-environment in an emergency scenario. Understanding the actions that high skilled riders do that make them better than less skilled riders would provide key knowledge to improve training methods. Effective rider training methods are necessary for the development of adequate braking proficiency in response to emergency situations in order to increase safety and reduce crashes and their fatal consequences.

3. Preliminary Investigations

Three preliminary investigations were carried out to help to formulate the main hypothesis of the thesis and focus the areas of the core research. The three investigations are:

- Rider behaviour based on in-depth accident data
- Rider behaviour based on naturalistic studies
- Instructor needs and preferences - *Questionnaire for Instructors (Instructors Needs and Attitudes)*

These three studies aim to identify the strategies and reactions during emergency situations associated to specific scenarios (in-depth accident data analysis) and to understand the braking behaviour in routine and in unexpected scenarios (analysis of naturalistic studies). Moreover, the needs and procedures of the instructors were studied with a survey to define the methodology according to their preferences and taking into account their knowledge.

3.1. Rider behaviour during accidents based on in-depth accident data

3.1.1. Introduction

As commented in section 2.2 one of the most likely reasons because the effectiveness of the training riding is questionable is that training does not address skills related to accident involvement. From the literature review it may be argued that there is a limited knowledge about which skills are particularly important for safe riding (Elliott et al., 2003; Simpson & Mayhew, 1990) and more particularly to specific risk scenarios. This section presents the study of in-depth data accidents carried out to obtain relevant information concerning the highest risk scenarios and riders' manoeuvres involved. Particularly, the aim of this first study is to understand how the lack of particular skills may have contributed to the crash/accident. The outcome of this first study will be a set of skills required for safe riding linked to specific high risk traffic scenarios. This may represent a valuable tool for rider training, where instructors will know the most realistic scenario linked to the skills needed for riding safer. Accordingly, the trainers will have the possibility to adapt the training exercise to the most suitable scenario with the means they have available (videos, multimedia, simulator or off-road training). In summary, this study wants to answer the following three questions:

- What are the highest risk scenarios?
- Which skills are critical for safe on-road operation of a motorcycle?
- What are the most frequent crash scenarios associated to the critical skills?

3.1.2. Methods

This study is based on the analysis of the motorcycle crash data collected by the MAIDS project (ACEM, 2003). The MAIDS database was collected in five European countries (France, Germany, Netherlands, Spain and Italy) from 1999 to 2000. The sample contained a total of 921 PTWs accidents with injured PTW rider with approximately 2000 variables, as well as data from a control group of 923 PTWs riders (ACEM, 2003). Although this database is more than ten years old, it still represents the largest and most comprehensive in-depth database of PTW accidents available today in Europe.

From all the 921 crash cases, those involving a mofa as the type of PTW were filtered. In addition, crashes occurred as a consequence of impairment from alcohol or drugs, and those due to mechanical problems were excluded. The total number of crashes extracted after using the above querying parameters was 803 (320 mopeds and 483 motorcycles). These samples were classified into 25 different accidents configurations by the MAIDS project.

Variables Analysed for Training strategies

The data analysis followed two different approaches. Firstly, we compared the demographics of accident cases with the control group to determine which characteristics were over-represented in the sample crashes. The variables selected were: age, gender, days per year ridden, distance per year, past traffic violations, type of training (official/regulated vs not official/regulated) and need of eye correction (glasses or contact lenses).

Secondly, we analysed each crash scenario to understand and identify the competencies needed by the rider to increase safety in each case. This analysis considered four aspects: 1) Frequency distribution of Crash Scenarios including crashes with all types of injury and including only crashes with severe injuries (MAIS3+); 2) Primary accident contributing factor by scenario with four categories based on the human information processing mechanism (detection, comprehension, decision and execution); 3) Evasive manoeuvres performed by multivehicle collision scenario; 4) Speed and time to collision (TTC).

From the 25 accident configurations 16 configurations were selected corresponding to 82.8% of the data (665 cases of 803). The aim was to focus on the scenarios with relevant information to assess whether motorcyclists could avoid the crash by improving their riding skills (hazard awareness, control skills or risk behaviour). Accordingly, accident configurations like "Other vehicle impacting rear of the PTW" were excluded, since only scenarios where PTW rider could perform an action to avoid the collision were considered. After that, the 16 accident configurations selected were merged into 7 scenarios (4 with intersections collision, 2 with collision without intersection and 1 single vehicle collision; see Figure 3-1) to facilitate the interpretation of the conclusions for training applications and to increase the statistical power. The merging criteria was based on the kinematic behaviour of the PTW and car up to the precipitating event, and followed similar approach to the study of Penumaka et al. (Penumaka et al., 2014) and the PISA project (PISA Project, 2006; Savino et al., 2010).

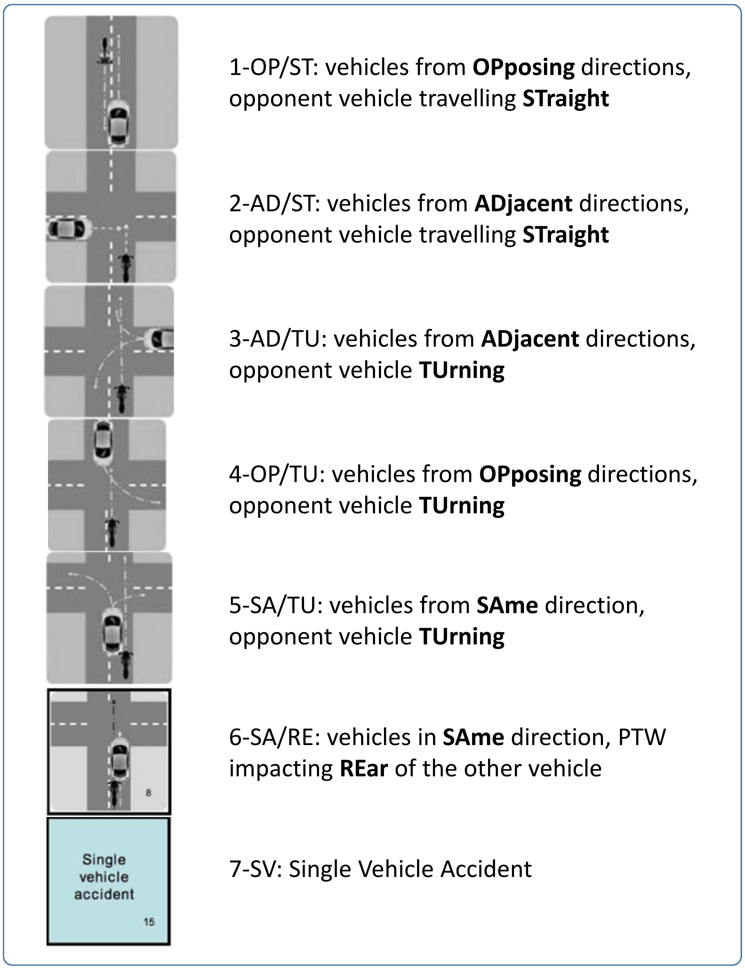


Figure 3-1. Definition of the configurations selected for the MAIDS analysis

Data Analysis

For crash-control study, Chi-square tests were used to find the over- and underrepresented factors in demographics. Pearson's chi-square test with odds ratio (O.R.) were used to determine the primary accident contributing factors and identify the evasive manoeuvers that were over-represented in the different categories of scenarios. For the odds ratio analysis, the original categorical variables were recoded as sets of dichotomous variables.

3.1.3. **Results**

Crash Cases vs Control Group

Only *rider age* was a significant factor related to crashes (see Figure 3-2). The group of riders between 18-27 are years old have a higher risk to be involved in accident since were overrepresented in sample of accident cases (p<.005, Chi-Square Test; Odd ratio of 1.48).

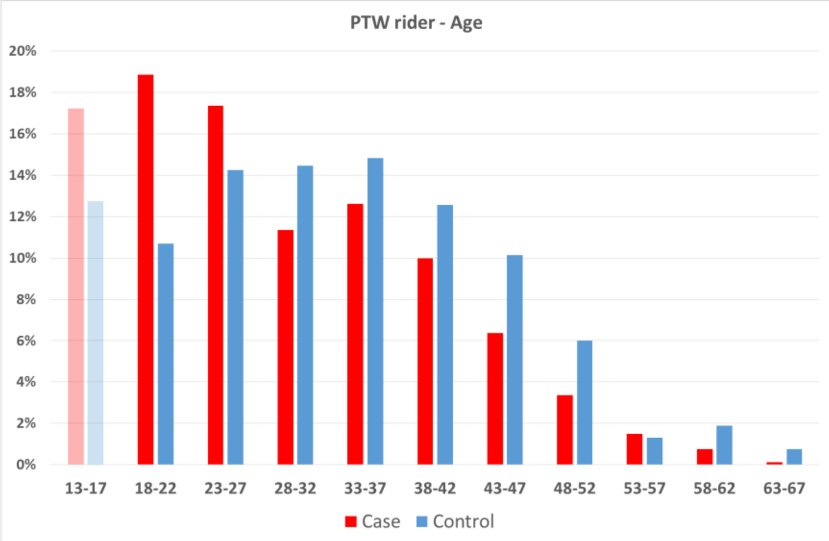


Figure 3-2. Distribution of ages for accident cases and control group

One factor of special interest for this thesis such as *motorcycle training* was not significant (p=.297) when comparing official training (compulsory or voluntary) with the rest (friends, family, self-training or no training needed). No official training represented 42.2% of the accident cases and 39.3% of the control cases. Gender was neither a factor of risk of crashes in general (p=.455) with women representing 13.1% of the accident cases and 14.3% of the control cases. Same absence of significant effect was found in the rest variables days per year ridden, distance per year, past traffic violations, and need of glasses or contact lens.

Distribution of Crashes Scenarios

The frequency distribution of the crashes by scenario defined by MAIDS and by clustered accident case (CAC) scenario considered in this thesis is shown in Table 3-1 and Figure 3-3a. The seven merged scenarios defined (Figure 3-1) represent 82.8% of the data (665 cases of 803). In addition, the data has been segmented by severity injured (
Table 3-2). Injuries from crashes were considered severe if they were MAIS3+.

The results shows that collision with other vehicle coming straight from an adjacent road (2-AD/ST) is the most frequent scenario (Figure 3-3a). 5-SA/TU is the second most frequent crash scenario, but it is less frequent in the crashes with severe injuries (see
Table 3-2 and Figure 3-3b). 4-OP/TU is the case more usual associated with severity (17% of the cases). It is also seen that the cases with severity are more than three times less frequent

that non severe ones (total 803 cases, severe injury 182 cases, and 621 cases of non-severe injury).

Table 3-1. Frequency of crashes by Scenario. (N=803 cases, including Mopeds; excluding Mofas)

Merged Scenario	Freq.	Scenario defined by MAIDS	Freq.
1- OP/ST	7.3%	head-on collision of PTW and OV	5.6%
		sideswipe, OV and PTW travelling in opposite directions	1.7%
2- AD/ST	16.9%	PTW into OV impact at intersection; paths perpendicular	9.6%
		OV into PTW impact at intersection; paths perpendicular	7.3%
3- AD/TU	12.5%	OV turning left in front of PTW, PTW perpendicular to OV path	9.8%
		OV turning right in front of PTW, PTW perpendicular to OV path	2.6%
4- OP/TU	11.8%	PTW & OV in opp. dir., OV turns in front of PTW, PTW impacting	9.3%
		PTW & OV in opp. dir., OV turns in front of PTW, OV impacting	2.5%
5- SA/TU	16.7%	PTW overtaking OV while OV turning left	6.5%
		OV making U-turn or Y-turn ahead of PTW	4.4%
		sideswipe, OV and PTW travelling in same directions	3.5%
		PTW overtaking OV while OV turning right	2.4%
6- SA/RE	6.5%	PTW impacting rear of OV	6.5%
7- SV	11.1%	PTW falling on roadway, no OV involvement	5.5%
		PTW running off roadway, no OV involvement	5.2%
		other PTW accidents with no OV or other involvement	0.4%
OTHER	17.2%	PTW falling on roadway in collision avoidance with OV	4.7%
		OV impacting rear of PTW	2.2%
		other	2.1%
		PTW impacting environmental object	1.9%
		other PTW/OV impacts	1.6%
		PTW impacting pedestrian or animal	1.5%
		PTW turning L in front of OV, OV proc in either direction perpendicular to PTW path	1.1%
		OV entering roadway failing to yield to PTW right of way	1.1%
		PTW running off roadway in collision avoidance with OV	0.6%
		PTW turning R in front of OV, OV proc in either direction perpendicular to PTW path	0.2%

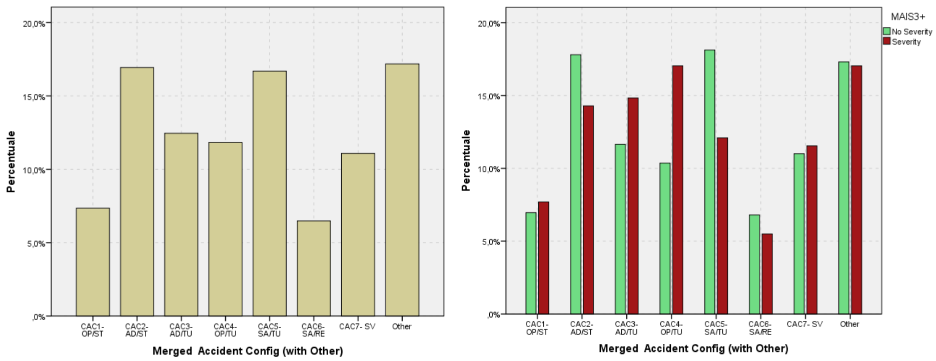
PTW: Powered-two-wheeler; OV: Other Vehicle

Table 3-2. Distribution of crash scenarios: complete sample and filtered by severity (MAIS3+).

	Total		MAIS3+	
	(N)	Perc. (%)	(N)	Perc. (%)
1- OP/ST	59	7,3	14	7,7
2- AD/ST*	136	**16,9***	26	14,3
3- AD/TU	100	12,5	27	14,8
4- OP/TU*	95	11,8	31	**17,0***
5- SA/TU	134	16,7	22	12,1
6- SA/RE	52	6,5	10	5,5
7- SV	89	11,1	21	11,5
Other	138	17,2	31	17,0
Total	803	100,0	182	100,0

The two merged scenarios representing collision with other vehicle in a road without intersections are the less frequent with less than 8% of frequency per scenario. These scenarios are ‘other vehicle in opposing direction going straight’ (1-OP/ST) and ‘other vehicle in same direction with PTW impacting rear’ (6-SA/RE).

Figure 3-3b shows that the clustered accident case CAC4-OP/TU is the case more frequent for severity accident. In fact, the results revealed that 30.8% of the PTW’s crashes with configuration 4-OP/TU presented severe injuries (MAIS3+), with a risk of severe injury 1.8 higher than the rest of configurations (odd ratio 1.8; p = .015).



a) b)

Figure 3-3. Distribution of PTW crashes scenarios from MAIDS database.

Primary accident contributing factor

The results obtained from the distribution of the variable *primary accident contributing factor* per accident configuration gives some keys in order to associate training skills with scenarios. Figure 3-4 shows the distribution of the most representative factors. The sum of all the contributing factors per each scenario in most cases is less than 100% because Figure 3-4 shows only the most representative factors.

Detection error by other vehicle in intersection collisions

Figure 3-4 illustrates how in the 4 merged scenarios corresponding to intersections (configurations 2/3/4/5) the main factor is “other vehicle driver failure”, with detection failure as the most usual failure caused by other vehicle (named *perception* failure in MAIDS). This is especially representative in the merged scenario 4-OP/TU with more than 60% of the cases. Defensive riding and hazard awareness are most important skills related to this information.

Detection and Decision error by rider in non-intersection collision

On the contrary, in the scenarios that are not directly related to intersections (1-OP/ST and 6-SA/RE), the primary contributing factor of the accident is “motorcyclist failure”. The most common failures for rear end collisions of the PTW (6- SA/RE) are detection of the hazard (28%) and for collisions with other vehicle coming in opposite direction (1-OP/ST) failures in decision (25%) (e.g. overtaking).

Execution error in single vehicle collision

The failures related with single vehicle crashes (7-SV) are mostly related to failure in the decision (21%) (e.g. going faster than required) and in the execution of the manoeuvers (20%) - named *reaction* in MAIDS - (e.g. wrong trajectory bending a curve) and with less frequency other external factors such as roadway defects or adverse weather not presented in Figure 3-4.

Other factors

The results represent a guideline to understand the lack of competencies in different scenarios for training purposes. In addition, some information provided help to the definition of scenarios during training activities with simulators, for instance, if configuration 3-AD/TU is simulated, view obstruction is a relevant factor to consider.

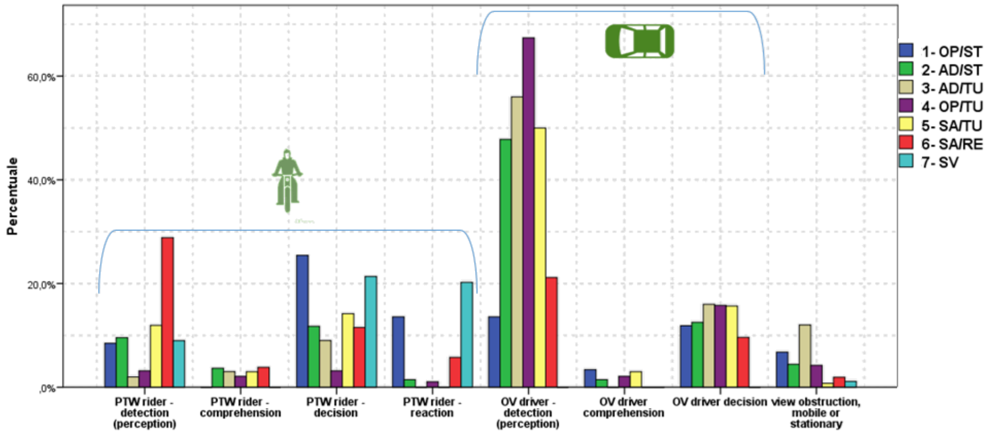


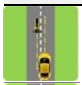
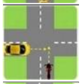
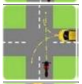
Figure 3-4. Relation between Primary accident contributing factor and Scenario

Evasive manoeuvres

Results of frequency distributions of scenarios per evasive manoeuvre is represented in Figure 3-5. In general terms, braking is the most common manoeuver (48.1%) followed by no manoeuver (32.7%) and swerving (13.3%) (Table 3-3). Results of distributions of scenarios per evasive manoeuvre is represented in Figure 3-5. It has been found that the more frequent evasive manoeuvre is braking for most of the scenarios. The scenario of “intersection where another vehicle is merging from an adjacent road for turning later” (3-AD/TU) is the one where braking is more present (60.6%).

As can be seen in Table 3-3, almost one third of the times (32.7%) riders did not perform any evasive manoeuver. This is a significant proportion and may be related to different factors such as how unusual or unexpected the hazard stimulus is, how many solutions the riders have under consideration or how fast is the perception-action process under constrained time. Less experienced riders or with less automatism in the emergency braking manoeuver may get into panic mode, instinctively reacting with either freeze or fear responses (Dilich, Kopernik, & Goebelbecker, 2002).

Table 3-3. Distribution of evasive manoeuvers per clustered accident case

		None	Braking	Swerving	Other	N
	1- OP/ST	36.2%	37.9%	13.8%	12.1%	58
	2- AD/ST	47.1%	39.0%	9.6%	4.4%	136
	3- AD/TU	18.2%	**60.6%**	15.2%	6.1%	99
	4- OP/TU	31.6%	**53.7%**	9.5%	5.3%	95
	5- SA/TU	41.8%	39.6%	16.4%	2.2%	134
	6- SA/RE	21.2%	**57.7%**	15.4%	5.8%	52
	Overall	32.7%	48.1%	13.3%	6.0%	574

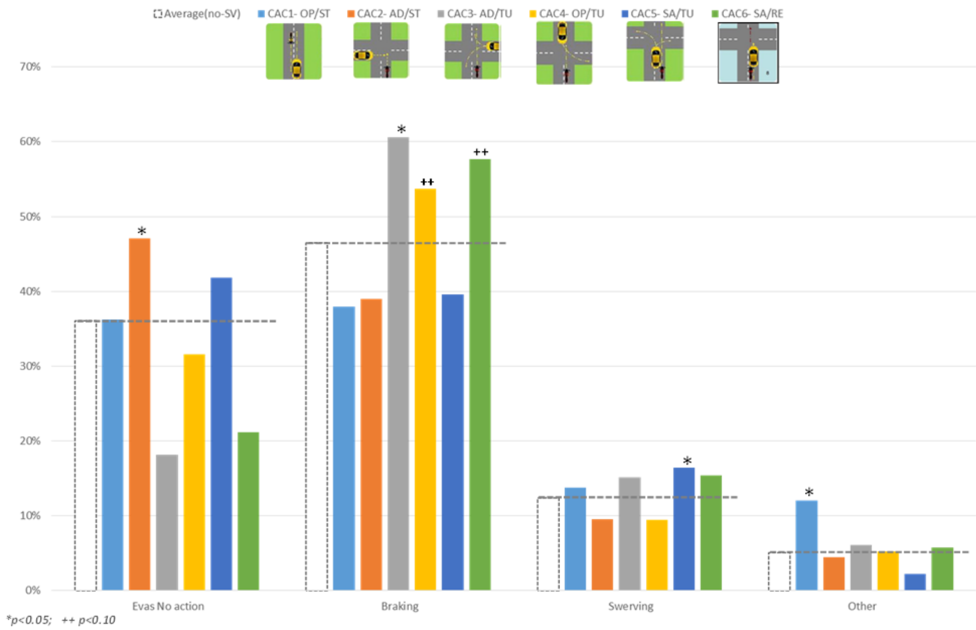


Figure 3-5. Relation between *Collision Avoidance Manoeuvre* and *Scenario* based on MAIDS data

After knowing the frequency of the different evasive manoeuvres by scenario, it was checked if concerning the MAIDS evaluators the selection of the avoidance manoeuver was correct. According to MAIDS evaluators, excluding 205 cases where the rider did not perform any avoidance manoeuver, the riders selected the correct evasive manoeuver in 82.2% of the cases, 15.4% did it wrong and 2.4% the results is unknown. The selection was mostly correct in all the scenarios (from 76.3% of 1-OP/ST to 88.9% of 4-OP/TU). Therefore, it can be considered that in the case that riders would have selected the right manoeuver in all the accidents the distribution of the evasive manoeuvres performed by scenario would be similar to the one showed by Figure 3-5. This also suggests that the collisions in most cases was not due to a bad decision making and that skills needed to face the different scenarios are not biased and correspond in fact to the one presented.

Table 3-4. Chi^2 Test analysis and Odds ratio of prevalence of evasive manoeuvers per scenarios

Manoeuvre	Scenario	*p*	OR	Frequency
Braking*	3- AD/TU	.002	1.96	61%
Braking++	6- SA/RE	.067	1.69	58%
Braking++	4- OP/TU	.086	1.45	54%
Evas No action*	2- AD/ST	.006	1.68	47%
Swerve*	5- SA/TU	.031	1.77	16%
Other*	1- OP/ST	.048	2.31	12%

**p<0.050; ++p<0.100*

The results of the Chi square and Odd Ratio tests revealed that 3-AD/TU is the scenario where braking is the most frequent evasive manoeuver (odd ratio 1.96; *p*=.002). Braking is also overrepresented in 6- SA/RE and 4- OP/TU where this manoeuver was executed in 58% and 54% of the cases respectively (odd ratios and *p* values in Table 3-4). On the contrary, in the case of intersections where other vehicle is merging and crossing straight (2-AD/ST) the riders did not perform any evasive action in most of the cases, probably because of the short time between hazard detection and crash impact. Swerving is the least performed manoeuvre with similar distribution for most of the scenarios. The scenario where “other vehicle is turning while PTW rider is overtaking” (5-SA/TU) is the one where swerving is the most represented (odd ratio 1.77).

Speed and time to collision

The posted speed limits for the collision cases is 50km/h in the most of the cases for all the scenarios except for “single vehicle accident” (7-SV), where 100km/h is just as predominant (Figure 3-6). The average impact speed is in most cases between 40 and 60 km/h (mean: 44.4km/h; S.D.: 26.1km/h). The distribution of the impact speed was similar or lower than the posted speed limits of the roads, although in 21% of the cases the impact was at a speed 10% higher than the posted limit (i.e. there was a speeding factor).

MAIDS study also estimated the time from precipitating event to impact. The average time from precipitating event to impact is 1.86 seconds (S.D. 1.23) as can be seen in Table 3-5 with the rest of values scenario.

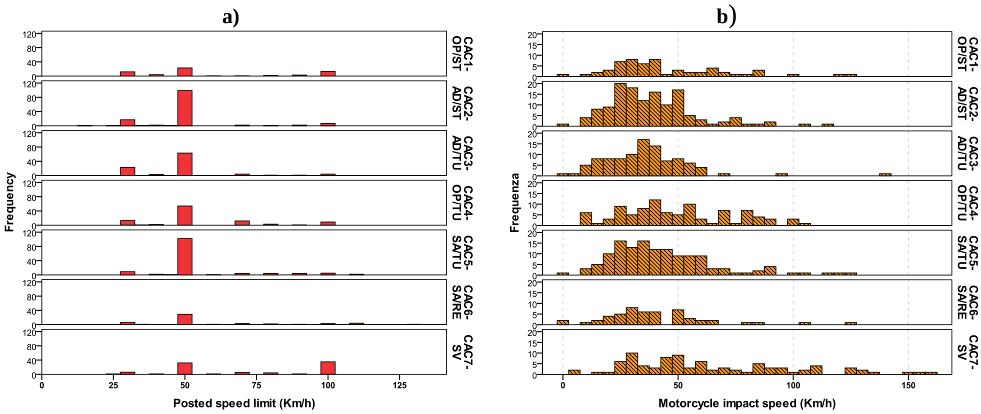


Figure 3-6. Histograms by merged scenario: a) posted speed limit (km/h); b) Impact Speed (km/h)

Table 3-5. Calculated time from precipitating event to impact (sec)

Clustered Accident Config	Mean (s)	S.D.	N
1- OP/ST	1.68	1.19	58
2- AD/ST	1.94	1.20	136
3- AD/TU	1.98	1.09	96
4- OP/TU	2.00	1.38	94
5- SA/TU	1.73	1.10	133
6- SA/RE	2.24	1.65	52
7- SV	1.54	1.11	83
Total	1.86	1.23	652

How it is considered the precipitating event is not defined in the report of the methodology (ACEM, 2003). The values are estimations based on accident reconstruction and only naturalistic studies can provide a reliable value, nevertheless, it works as a reference to understand the accidents. If the average time is around 2 seconds, for a travelling speed of 50km/h (13.88m/s) in case of braking to avoid a collision (and considering that the other vehicle is not going through the PTW), the deceleration average needed will be at least 6.94m/s2. According to literature, this deceleration is only available to experts in a controlled harm-free environment without the stress/panic of an emergency situation.

3.1.4. **Conclusions**

In summary, from this first study it can be concluded:

1) Intersection are the highest risk scenarios with other vehicle in opposing trajectory turning in front of the rider as the highest risk considering crashes with severe injured and vehicle coming perpendicular from adjacent road as the most frequent crashes scenario.

2) The crash likelihood for riders with official motorcycle training was not found to differ from that of riders who had other types of informal training. The parameter motorcycle

training is difficult to classify in a robust way considering different kinds of training by countries, region or even riding school, so this variability makes it hard to set conclusions about the effectiveness of a specific training, however in general context it may be suggested that the training is not a significant factor to be involved in a crash.

3) Detection failures from other vehicles as the main contributor factor shows how critical are perception skills and defensive riding in risk scenarios.

4) Braking is the most important evasive manoeuver and generally used to avoid collisions. Improving braking skills will reduce crashes and injuries.

5) Riders did not perform any evasive manoeuvre in almost one third of the cases. Riders may go into freezing mode because of panic if they do not generate properly the automatism of hazard perception-evasive action.

6) Accidents are generally in roads with speed limits of 50km/h (except for single vehicle crashes) and the impact speed is mostly between 40 and 60 km/h.

The results of this analysis have identified the riding skills most needed to reduce accidents in the highest risk scenarios. Figure 3-7 shows an example of how to use this information in the context of education and training for safety.

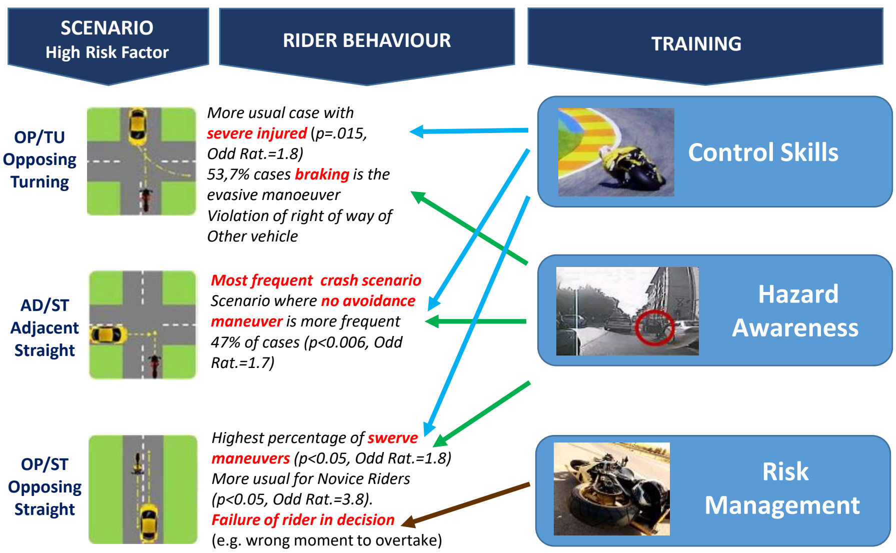


Figure 3-7. Summary of Methodology to address training of the skills associated with high risk scenarios. Source: (Huertas-Leyva, Baldanzini, Savino, & Pierini, 2015)

The thesis shows the direct relationship between the most frequent lacks of skills associated to the most frequent scenarios. This is a valuable knowledge that may be used in the development of efficient training emulating specific scenarios to enhance the competencies of the riders in specific skills. One way to implement this knowledge is using riding simulators, where it is possible to define scenarios in controlled experiments. The implementation may also be done with simpler methods such as lectures with discussions showing videos of the most critical scenarios and explaining the right decisions and actions to the trainees. More complex methods may emulate a real-world scenario in a controlled area (e.g. parking lot) with an instrumented training vehicle, similar as the approach of this research.

3.2. Rider behaviour based on Naturalistic studies

3.2.1. Introduction

The aim of this second study was understanding the behaviour of the riders more deeply and in different contexts through two analyses of two different naturalistic studies. The first study analysed data from a naturalistic study with 5 riders on a 300cc scooter in Florence performed by the University of Florence in the EU 2BESAFE project. The second study analysed data from a naturalistic study of 11 cyclist riding e-bikes (pedelecs) in Gothenburg done by Chalmers University of Technology in the EU project (EBIKE safe).

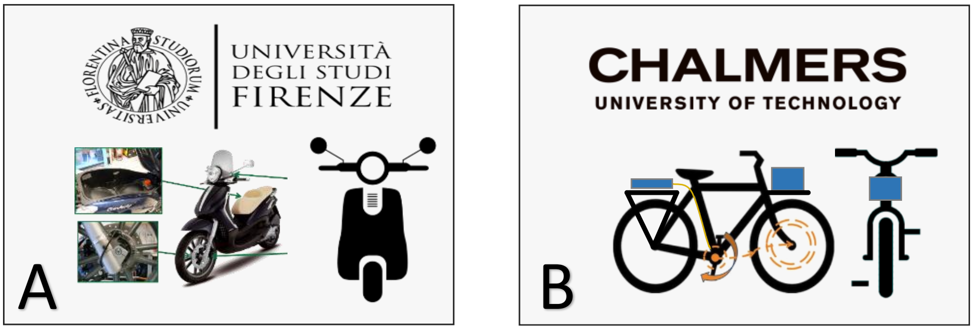


Figure 3-8. a) Instrumented scooter; b) Instrumented electric bicycle

In these two studies, a systematic analysis of rider behaviour during braking manoeuvers was conducted with the support of naturalistic data. The Naturalistic studies provide an unequaled method for investigating riding behaviour in the real world in which the riders regularly experience traffic conflicts and may need to perform avoidance manoeuvers, such as hard braking, to avoid crashing. The specific objectives of the study were the classification of riders according to a macro-behaviour; and the use of the front and rear brake.

Although pedelecs have completely different geometry, weight and power engine (250W), both scooters and pedelecs have in the front brake most of the potential power to stop, and in both vehicles combined braking is the most effective way of braking. Considering that different types of PTWs require different ways of riding, the comparison may give relevant knowledge about similitudes and differences in the behaviour circulating in a city between users of a medium engine size scooter PTW and users of electric bicycle, both with two brake hand levers.

3.2.2. Use of Brakes: Scooter

Methods[2]

Data were collected as part of the EU funded research project 2BESAFE within a study on naturalistic riding (Baldanzini et al., 2010). Five volunteer PTW riders were recruited and were given an instrumented PTW to use in everyday life conditions. Each rider used the PTW for a period ranging from 1 up to 2 months.

The set of recorded signals was comprised of: wheel speed (front and rear), brake pressures (front and rear circuits), IMU data with three axis of linear acceleration; angles and angle rates; longitudinal speed; throttle position; steering angle; GPS position; turn signals; brake activation; and 2 video cameras positioned to capture the frontal environment and the rider's head. Data collection was performed with a scooter (Piaggio Beverly Tourer 300ie). This choice reflected the fact that in the Florence area most PTWs are scooters used for daily commuting. Data acquisition was performed in the period January to October. The scooter was not equipped with any brake assist device (e.g. ABS or Combined Braking System –CBS–).

The raw dataset of the UNIFI unit was used in the present study. The sample included three scooter riders and two motorcycle riders that used mopeds for commuting. More details of the participants are reported in Table 3-6.

Table 3-6. Rider characteristics

Subject	Gender	Age [years]	Experience [years]	Vehicle owned	Frequency of riding	Annual mileage [km]	Motivation for riding
Rider 1	Male	28	12	Moped & motorcycle	Daily	5,000	Commuting & leisure
Rider 2	Male	34	18	Moped & sport motorcycle	Daily	7,000	Commuting & leisure
Rider 3	Male	37	19	Scooter	Daily	2,000	Commuting
Rider 4	Male	29	7	Scooter	Daily	10,000	Commuting
Rider 5	Male	41	24	Scooter	Daily	10,000	Commuting

Data processing

Raw data were processed to identify all braking events recorded during normal and safety relevant riding conditions. Specifically, in this study the following signals were considered: braking pressure of the front and rear circuits; longitudinal deceleration; wheel speed (front and rear); and longitudinal velocity.

[2] Methods published in (Baldanzini, Huertas-Leyva, Savino, & Pierini, 2016)

After filtering, all data corresponding to a longitudinal speed lower than 0.55 m/s (2.0 km/h) were excluded from the event identification. In fact the threshold represents a quasi-static condition and thus it is not of interest for investigating riding tasks.

The automatic identification of braking events was integrated with a validation process, based on a set of minimal requirements (Table 3.7) to be simultaneously met in order to accept the braking event in the analysis.

Table 3-7. Thresholds for automatic validation of braking events

Signal	Threshold
Brake pressure	0.2 [bar]
Minimum pressure range within the braking event	1.5 [bar]
Duration of the braking event	0.4 [s]

Braking events were characterized through the definition of a set of parameters, designed to extract the most relevant information of the braking action. Table 3.8 shows those parameters of interest for the study of the use of braking.

Table 3-8. Description of parameters used to characterize the braking event.

Parameter	Description
Type of braking event	Identifies the type of braking action: only front or rear braking; combined braking.
Relative position of braking action	Applies to combined braking events. It analyses the sequence of activation of the front and rear circuits discriminating between the following different actions: a) action starts with rear or front braking only and ends respectively with front or rear braking only (intersected braking events); b) action starts and ends with rear braking only (front in rear braking); c) action starts and ends with front braking only (rear in front braking).
Maximum pressure	Maximum pressure value in each circuit (Front and Rear) and their sum.
Deceleration	Maximum deceleration and mean deceleration within the event.

Results

Datasets of different sizes were obtained according to different mileage and usage: 2603, 3039, 1321, 3028 and 1570 braking events were respectively extracted for rider 1 to 5. Since during acquisition, one or more sensors occasionally failed, not all signals were always available and thus a share of events could not be completely characterized according to the specified set of parameters. During this first analysis of the dataset, focus was restricted to the fully characterized events and thus the datasets reduced to 177, 1183, 96, 1631, and 486 for rider 1 to 5 respectively (3573 braking events in total).

Descriptive analysis

A macro analysis of the datasets was performed to check the presence of different braking styles. Type of braking event and relative position of braking action were candidate parameters for the investigation. A Pearson Chi square test versus riders confirmed their significance as descriptive parameters ($p<.001$). Detailed figures of the analysis are reported in Table 3-9. All riders performed predominantly combined braking manoeuvers. Nonetheless it was possible to distinguish between the behaviour of riders 1 and 3 (with respectively 87.0% and 83.3% of combined braking), and the behaviour of the remaining riders (in the range 68.4% to 73.7%).

Table 3-9. Distribution per rider of: braking type and braking pattern [%].

	Type			Position		
Id	**Front**	**Rear**	**Comb.**	**Rear in Front**	**Front in Rear**	**R & F Inters.**
ID1	9.0	4.0	87.0	38.3	16.9	44.8
ID3	12.5	4.2	83.3	61.3	11.2	27.5
ID2	0.3	28.9	70.8	5.1	79.8	15.1
ID4	2.7	28.9	68.4	8.8	65.4	25.8
ID5	3.5	22.8	73.7	10.0	61.2	28.8

A breakdown of combined braking data confirmed the existence of clear distinctive behaviours that were common to this group of riders. On one side the group of rider 2, 4 and 5 was characterized by the highest share of *rear only* braking events (22.8% to 28.9% vs 4.0% to 4.2%). In addition, this group showed lower proportion of combined braking with the majority of the braking events (61.2% to 79.8%) initiated and ended with the rear brake using front brake for a shorter time (‘*front in rear’* braking).

On the other side, the group of riders (rider 1 and 3), was characterized by a higher frequency of *front only* braking events (9.0% to 12.5%) and also the highest share of combined braking (83.3% to 87.0%), either with front and rear brake on the same level or with a preference for front brake.

Brake use by level of deceleration: Comfort vs. Hard/Demanding braking

The next step was to know how the brake deceleration were distributed in order to find the thresholds that could be related to different traffic scenarios (e.g. soft brake to circulate in dense traffic, stop braking in a traffic light or hard braking due to traffic conflict with other road users). Figure 3-9 shows the histogram of the deceleration for the 3573 braking events detected. The distribution shows two different deceleration zones: the first one considered the comfort or soft area of deceleration between 0 and $2 m/s^2$; the second zone may be understood as a more demanding braking with deceleration higher than $2 m/s^2$.

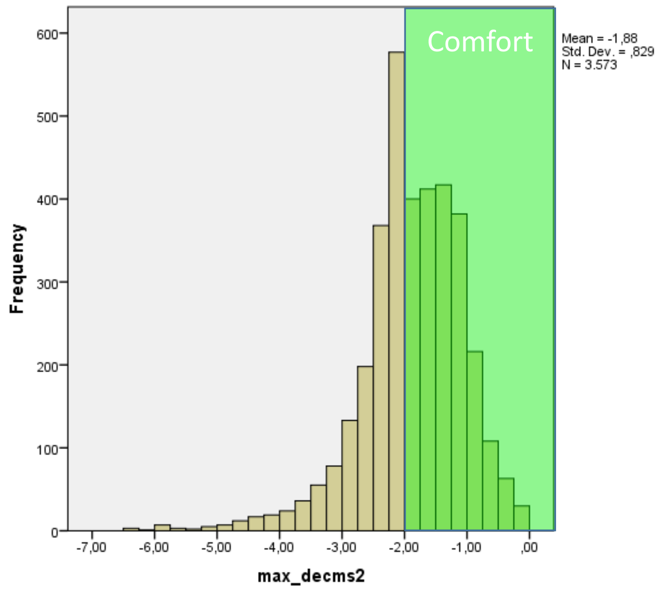


Figure 3-9. Histogram of deceleration [m/s^2] of the braking events (green area represents comfort braking)

Based on these results, the same analysis of the use of the brakes was done with a subset of decelerations equal or higher than 2 m/s^2 and another subset with decelerations lower than 2m/s^2. The aim was to know if it was possible to confirm the hypothesis 1 that the use of only one brake (single braking) is exclusively for the comfort area of decelerations lower than 2m/s^2 in all the riders. As shown in Table 3-10 for comfort braking the frequency of single braking is higher in both groups, but in the case of the 'rear brake' riders the percentage is almost as high as the combined braking. These results were in part expected according to the hypothesis set. The results of the subset of 'hard/demanding' braking shows two different behaviours by group. The group of "front/combined" braking uses the combined braking in almost all the cases (99.9% and 100%). On the contrary the group of 'rear brake users', in spite of the increase of combined braking cases, still remains with prevalence between 4.7% and 11.5% of single rear braking. The hypothesis set is only valid for riders using predominantly the front/combined braking, but not strictly for the group of 'rear brake' users.

Table 3-10. Comfort vs hard braking. Distribution of use of braking during naturalistic scooter

	Front Brake – Higher Use				Rear Brake – Higher Use					
	ID1		ID3		ID2		ID4		ID5	
Brake Action	<=2m/s^2	>2m/s^2	<=2m/s^2	>2m/s^2	<=2m/s^2	>2m/s^2	<=2m/s^2	>2m/s^2	<=2m/s^2	>2m/s^2
Only Front	18.8	1.0	20.0	0.0	0.6	0.0	4.3	0.3	5.6	1.6
Only Rear	8.8	0.0	6.7	0.0	41.2	11.5	43.8	7.6	42.9	4.7
Combined	72.5	99.0	73.3	100.0	58.3	88.5	52.0	92.1	51.5	93.7
Total (N)	80	97	60	36	695	488	962	669	231	255

The final step was to analyse the maximum brake pressure (rear and front) values of the braking events to understand how the distribution of combined braking is for the two group of riders. The hypothesis 2 is that riders that use predominantly one brake (rear or front) use that brake predominantly during hard braking even if they perform a combined braking. It is important to notice that although the pressure values have a high correlation with the braking force, they do not provide a precise indication of the braking deceleration.

As shown in Figure 3-10 and Figure 3-11 there are differences in the distribution of the brake pressure between the two groups for ‘comfort’ and ‘hard’ braking. The scatter plots are divided by a line that represents same pressure distribution in front and rear brakes. If the mark of the brake event is placed on the top-left- of the graph, which means that rider is braking more with the front brake. On the contrary, if the mark is placed on the bottom-right- the rider is braking more with the rear brake. Figure 3-11 supports hypothesis 2, since based on the scattered plot it can be seen how the combined braking are placed more frequently in the half size of predominance of front braking for the group of riders 3 and 1 and more frequently in the half size of predominance of rear braking for the group of riders 5, 4 and 2. In each of the two groups there are riders that have a stronger preference to use more one type of brake (rider 3 for front brake and rider 2 for rear brake) and others that are closer to an equal distribution (rider 1 and 5). However, in terms of braking the rear brake provides not more than 30%-40% of the braking effectiveness of the PTW (depending of the geometry and weight distribution), while the front brake provides the larger part (Corno et al., 2008; Cossalter et al., 2004). An efficient braking in emergency situations, riding straight on dry surface, will need a fast and full activation of the front brake.

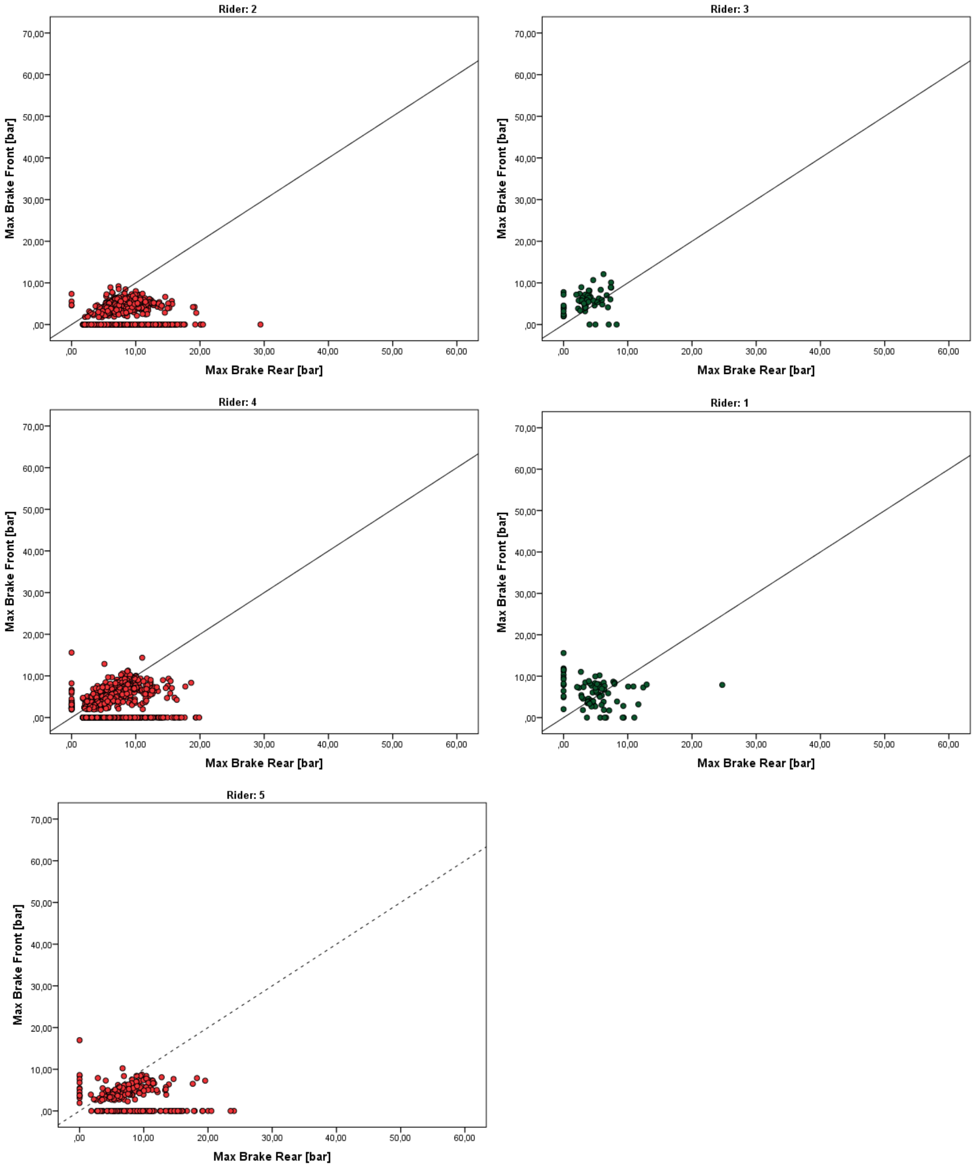


Figure 3-10. Distribution of Brake pressure for deceleration <2m/s^2.
X-Axis: Maximum Rear Brake Pressure (bar); Y-axis: Maximum Rear Brake Pressure (bar).
Left-Red: 3 riders predominant Rear Brake – Right-Green: 2 riders predominant Front Brake

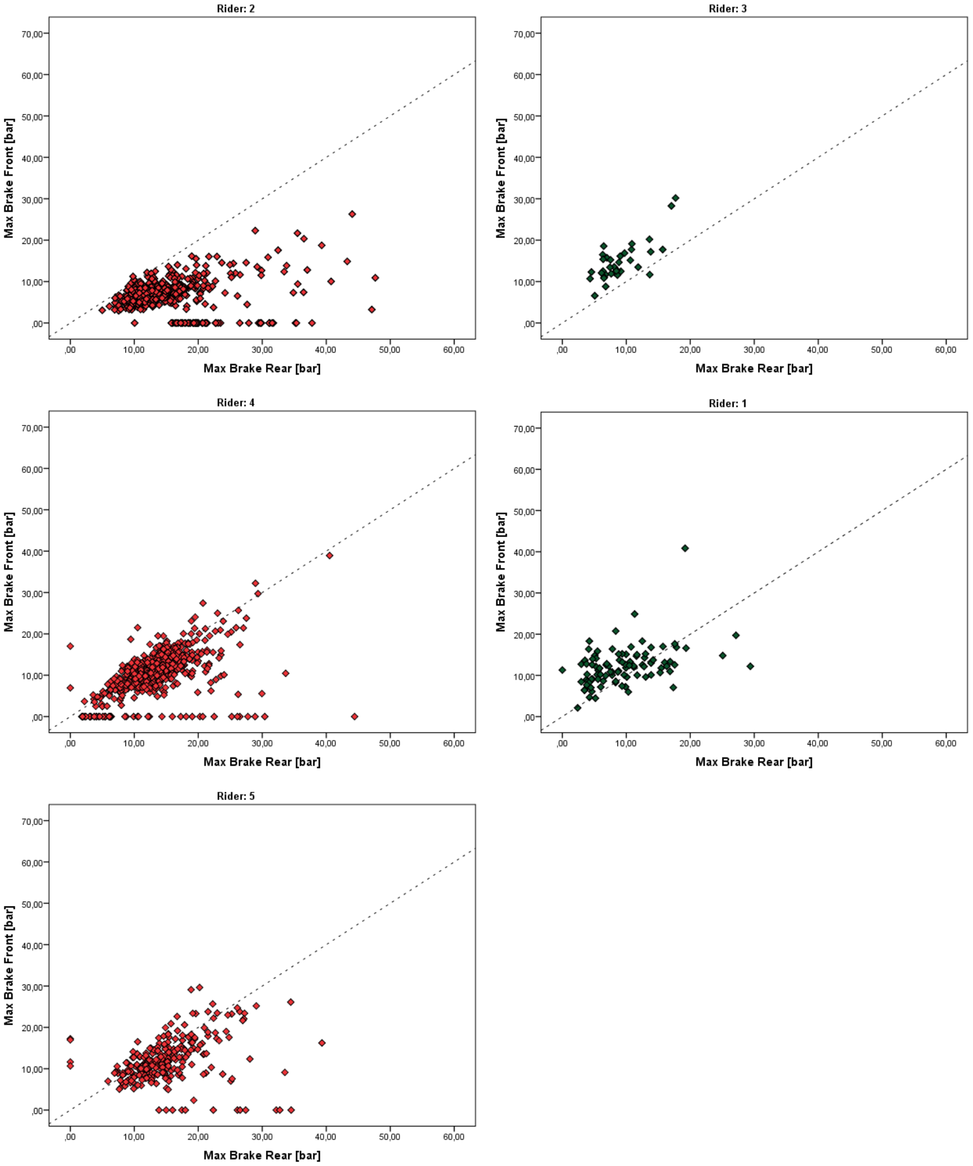


Figure 3-11. Distribution of Brake pressure for deceleration >2m/ s2. X-Axis X-Axis: Maximum Rear Brake Pressure (bar); Y-axis: Maximum Rear Brake Pressure (bar). Left-Red: 3 riders predominant Rear Brake – Right-Green: 2 riders predominant Front Brake

Conclusion

The results support the existence of clear distinctive behaviours that were common to this group of riders. In particular, 3 riders with a predominant usage of rear brake (alone or in a combined braking scheme) were identified; the 2 remaining riders used more combined braking (either with front and rear brake on the same level or with a preference for front brake) and also only front braking.

The results of this study suggest that there is a relationship between the use of brakes during 'comfort' braking in routine manoeuvers and the use of brakes during demanding braking. Riders that use single rear brake during comfort braking use also predominantly rear brake for hard braking, which means a non-efficient braking. This result is important in terms of safety, since a non-efficient braking in an emergency scenario requiring an evasive collision is critical. Future studies revising video registration of the hardest braking to check if they correspond to near-misses events may help to confirm the finding for emergency scenarios. A larger sample size of participant and a motorcycle with clutch and footbrake to activate the rear brake are recommended to verify whether these results can be generalised. However, the study did not find effect in the PTW owned by the participants, since the two motorcycle riders (riders '1' and '2') were distributed in different groups. This suggests that the pattern in the use of the brakes may not be directly related to the type of PTW ridden.

3.2.3. Use of Brakes: e-Bike

This research presents results from the analysis of data collected in the naturalistic study E-bikeSAFE (Dozza, Bianchi Piccinini, & Werneke, 2016) with e-bikes collected by Chalmers University at SAFER. The aim of the study was the understanding of the braking behaviour in terms of use of brakes - single rear, single front or combined braking. In addition the study compared the results of the overall braking events sample from the naturalistic study with a subsample of unexpected braking events to see whether there were changes in the pattern of the riders during higher demanding manoeuvers.

Methods[3]

For this analysis, data from the 11 participants riding on an e-bike (two weeks of data each one) were considered. The participant cyclists were regular bicycle riders. E-bikes from the study were specially equipped with two brake sensors (one for each wheel), a GPS, two inertial measurement units and one forward facing video camera. The e-bikes were also instrumented with a motor (250 W), a control unit, two brake switches, a throttle (only active up to 6 km/h in accordance with European regulations), and a rechargeable battery.

A total of 2204 braking events were identified following the method used by Johnson et al. (2015) combining the analysis of brake pressure (front and rear), braking activation (from switches on e-bikes only), velocity and longitudinal acceleration from the bicycles. Figure 3-12 shows an example of the data collected during braking events. For every brake event the

[3] The material and methods of this section were published in (Huertas-Leyva et al., 2018)

type of braking action was identified with three different levels: only front braking, only rear braking; combined braking.

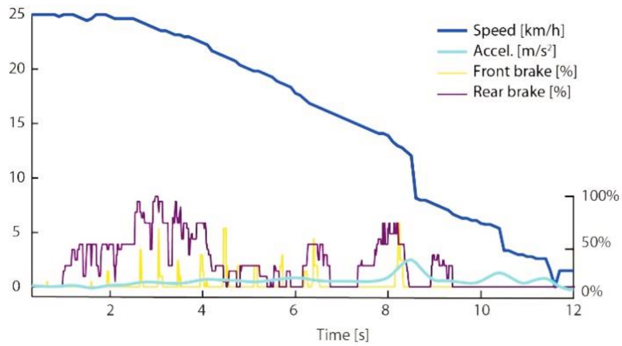


Figure 3-12 Example of a braking event. Velocity, brake pressure and deceleration during braking event. Source of data: SAFER

Unexpected event

A subsample with the braking events of five participants were selected to compare if the use of the brakes (single or combined) in an identified demanding situation (47 unexpected events) was the same that in routine riding. Unexpected events were selected by video analysis that identified whether braking was the consequence of reaction to avoid a collision due to a threat or conflict with other road users or obstacles—unplanned braking - or on the contrary it was a planned behaviour to pro-actively regulate speed—planned braking (for more information about the selection of unexpected events see Huertas-Leyva, Dozza, & Baldanzini (2018)). The analysis followed the internationally accepted definition of traffic conflict of Amundsen & Hydén (1977): '*A traffic conflict is an observable situation in which two or more road users approach each other in space and time to such an extent that there is a risk of collision if their movements remain unchanged*'.

Results

Table 3-11. Distribution of use of Braking during naturalistic study with e-bike (N=11 cyclists)

	Front predominant				*Rear predominant*					*Mix*		
Brake Action	*ID3*	*ID10*	*ID13*	*ID14*	*ID4*	*ID8*	*ID5*	*ID9*	*ID11*	*ID12*	*ID6*	Total
Only Front	88%	62%	59%	68%	21%	11%	15%	6%	12%	29%	45%	36%
Only Rear	6%	29%	34%	12%	65%	83%	72%	87%	83%	48%	22%	50%
Combined	6%	10%	7%	20%	14%	6%	13%	7%	6%	23%	33%	14%
Total (N)	239	21	267	160	108	195	495	186	144	98	291	2204

The results of the *type of braking* action analysis revealed that all cyclists used mainly single braking manoeuver during regular braking actions, and that in most cases cyclists had a 'predominant' brake (rear or front). A type of brake action was considered predominant when the prevalence of only Rear, only Front or Combined brake was higher than 50%. The results show two groups of cyclists with a predominant single brake (*Front Predominant* or *Rear Predominant*) and one group with no predominant type of braking, (*Mix*), see Table 3-11. Thus, the results show that predominant brake varies among the cyclists and that different cyclists may have different braking strategies.

Unexpected braking versus General pattern

The five participants of the subset corresponded to the three different groups (Front predominant, Rear predominant and Mix). After analyzing the unexpected braking events, it was found that the pattern of *type of brake* action changes compared to the general pattern (Table 3-12). The frequency of combined braking increased in all the cyclists during unexpected events. It is also noted, that in the unexpected braking events where combined braking was not applied, cyclists continued using mainly their 'predominant' brake no matter if it was rear or front brake.

Table 3-12. Distribution of use of Braking for Unexpected scenarios with e-bike (N=5 cyclists)

Brake Action	*Front predominant*				*Rear predominant*				*Mix*	
	ID3		*ID10*		*ID4*		*ID8*		*ID12*	
	All	*Unexpect.*	*All*	*Unexpected*	*All*	*Unexpected*	*All*	*Unexpected*	*All*	*Unexpected*
Only Front	88%*	40%*	62%*	50%*	21%	25%	11%	17%	29%	8%
Only Rear	6%	20%	29%	0%	65%*	50%*	83%*	25%	48%	0%
Combined	6%	40%*	10%	50%*	14%	25%	6%	58%*	23%	92%*
Total (N)	239	10	21	8	108	4	195	12	98	13

* most prevalent type of braking action

Conclusion

On e-bike, during routine braking, cyclists used single braking in most cases. The predominant brake may be front or rear brake depending of the preferences of the cyclist, what suggests that there is not a universal acceptance or knowledge of the most proper way to brake. Cyclists modify their operations braking, using more combined braking, when they face unexpected threats that usually require high deceleration. However, there are still high prevalence of single braking in the four riders that had clearly identified a predominant brake (rear or front). This single braking trend can represent a setback in terms of brake effectiveness in emergency scenarios, since combined braking is normally the best way to enhance the braking performance. However, giving braking instructions to the riders to achieve the optimum braking is hard task, since optimum distribution of rear and front brake depends on different factors, such as the design of the bicycle, the road surface friction, the grade of the path or even the scenario (straight line or turning/cornering).

3.2.4. Conclusions

The riders of the study with the 300cc scooter-type PTW used mostly combined braking. The behaviour found with e-bikes was different: all cyclist used mainly one single brake during regular braking actions instead of combined. Despite these differences, both studies have in common that in most cases riders had a ‘predominant’ brake (rear or front).

The results showed that there is not a generic established/adopted pattern about the proper way of braking among PTW riders with the scooter 300cc of the study, since riders that used rear as predominant brake also used less the front brake in combined braking losing effectiveness in the braking. The previous work of Sheppard et al. (Sheppard et al., 1985) presented similar findings based on test results, roadside observations and interviews. In that study authors also concluded that there is not a universal use of brakes, that very frequently riders use only one brake and that more often the rear brake was the predominant.

Although using combined braking is much less frequent in e-bikes during braking events, similar trend in the use of a predominant brake (front or rear) among electric bicycles were found and also similar relationship between the predominant brake used of brakes in unexpected events and the overall use of brakes. Further work is suggested to collect with interviews the motives of riders for the use of their predominant type of braking with PTWs and bicycles (e.g. stability, effect in efficiency, aware of front wheel lock). Another approach would be to study if the PTW riders that have used regularly bicycle before riding PTWs \`inherit\` from bicycles the motivational characteristics of use of brakes.

The main finding of this study is the relationship between the way riders brake in routine manoeuvers with the performing in demanding situations that require hard braking. An interpretation of the facts indicates the importance of setting a proper behaviour pattern even for comfort and routine braking. In emergency scenarios, in panic, for an early and fast response riders use mental shortcuts, mostly using the threat response from the limbic system without the cognitive processing of the sensory cortex (LeDoux, 2003). Thus, even if the riders know theoretically the proper way of braking, in emergency situations (with too short processing time available) the response will be mainly based on the previous experiences and the automatism created while riding. Further research is suggested to know if using combined braking with front brake predominant during routine manoeuvers reduces the cognitive workload of the decision-making process and also helps to create automatisms that bring to the correct use of brakes in emergency scenarios.

3.3. Instructor needs and preferences- Questionnaire for Instructors

A survey to know the needs of the instructors and their habits on teaching and learning was designed. The survey was implemented in a website to collect the answers from instructors from different regions of Italy to capture a diverse range of respondents. The answer of the participants was collected keeping the anonymity of the instructors to enable more freedom in the answers. The complete survey is included in Annex-3. The survey was answered by 19 riding instructors of whom 11 completed the questionnaire until the end. This section presents the most relevant results for this thesis: emergency braking test realism, instrumentation needs and feedback methods.

The instructors were asked about the relationship between emergency braking test and real-world. Only 3 of 11 instructors thought the license test for emergency braking reflects the skill level that riders need to have in real-world riding. When asked about the two most important features when evaluating practice attempts, instructors mostly look for balanced front and rear brake use (72.7%), followed by other secondary features such as the coordination and control of body movements (36.4%), the stopping at a specific place and stability of PTW at completion of braking (both 27.3%). At the same time most of the instructors indicated that the hardest task for the trainees is finding the right balance front and rear brake use (63.6%) and coordinating the body movements (54.5%). Although it was not in the pre-defined answers, many instructors noted the importance of scanning the environment and keep the look straight ahead during the exercise.

Concerning the type of feedback used, there is not a clear consensus in the most important type of feedback. Between the different options the instructors selected mainly the description of what could happen as a result, and the practical demonstration of how to correct the error (Figure 3-13). Asked about tools for teaching, most instructors (55%) considered PTW instrumented as one of the most important tools for teaching (Figure 3-14).

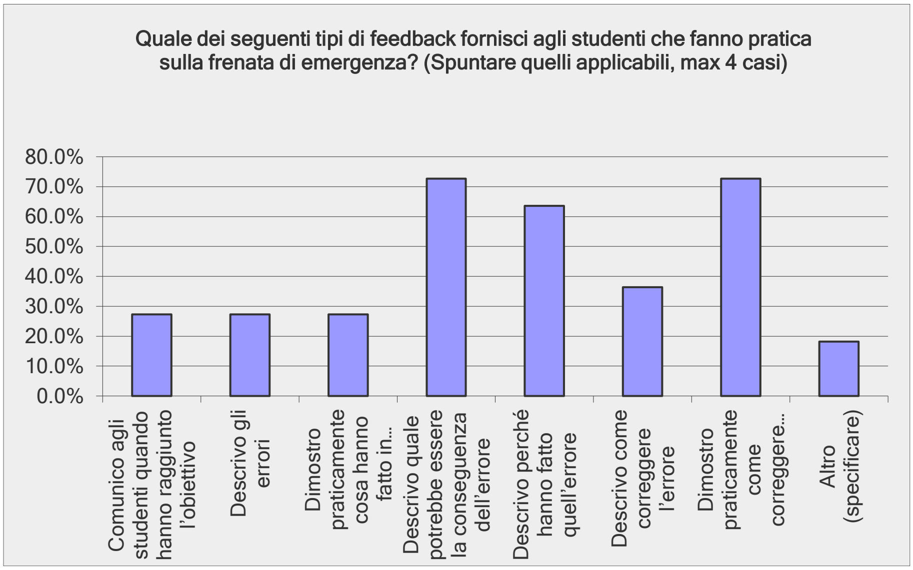


Figure 3-13. Importance of information as Feedback (1 minimum 6 maximum) – N=11

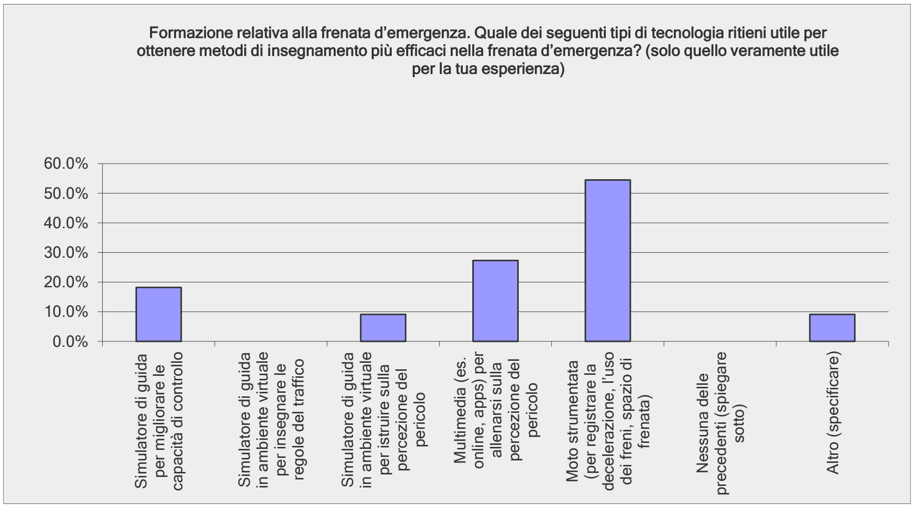


Figure 3-14. Most Useful Technology (55% of instructors that considered important) – N=11

The results of this study are preliminary and future steps will be done to increase the sample size to seek to ensure the significance of the findings presented.

3.4. Conclusion

Rider behaviour has been objectively assessed and evaluated using qualitative indicators delivered from in-depth accident data and from a quantification of rider behaviour in traffic conflict situations collected with naturalistic studies. This section summarizes the conclusions of the studies of this chapter as a complement of the state of the art presented in Chapter 2. The conclusions aim for defining an experiment able to identify and understand key components needed for effective training interventions that enhance safety in emergency scenarios. The section presents conclusions as strategic points for the design of the study that corresponds to the last chapters of this thesis.

1. Identification of the most critical skills/competencies needed in emergency scenarios

Braking is most critical control evasive manoeuver to avoid collisions in critical scenarios and also the hardest manoeuver to learn. It is necessary improving methods to teach how to brake correctly. In-depth accident study revealed that perception skills that aware the rider of a potential hazard in the shortest time is critical to avoid crash scenarios. The analysis of naturalistic studies has shown that in many cases riders do not use the brakes in an effective way because lack of knowledge or lack of practice. In addition, as it was pointed in the state of the art and supported by the instructors' answers, one key aspect of the training exercise is to be able to couple braking action with hazard perception. Only integrating this two components in a perception-action task, the skills learnt during training may be transferred to real world.

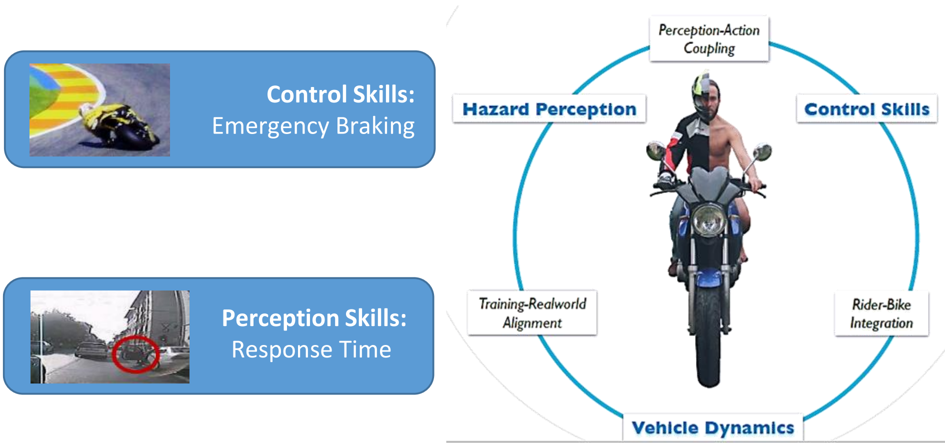


Figure 3-15. Scheme of the model of integration of control and perception skills

2. Use of technology as an added value tool to assess with objective indicators

Instructors demand tools to measure objectively the performance. The literature review pointed the need to have objective measures of the performance to understand the real needs of the riders to improve their competencies. A PTW instrumented will provide the data to

Figure 3-16. Instrumentation on PTW

understand the performance of riders with different skill levels.

3. *Design a real-world controlled braking task representative of a high risk scenario requiring perception-action*

Intersections with another vehicle making a left turn across a PTW's path (Opposing Vehicle Turning) is the most frequent scenario in severe injured accidents. This scenario requires mainly braking as evasive manoeuver and perception of the unexpected hazards, mostly violation of the right of way from other vehicles.

Figure 3-17. Scenario

A parking lot is necessary to emulate a realistic scenario where a car will turn in front of the test riders at a travelling speed of 50km/h (speed based on the results of section 3.1). The scenario provides also a component of defensive riding working in expecting the un-expectable, and teaching the importance of reducing the speed in dangerous points to have more time to process the information and react.

4. *Determine skill levels in braking performance*

The braking skills levels of the riders will be assessed measuring the deceleration during the emergency braking and the stop braking distance and comparing different rider profiles. In addition, measures from the inertial measurement unit and the steering will measure if the rider has a full control of the vehicle or was close to lose the control. The response time will be the indicator to assess the perception skills. Figure 3-18 shows the process of the braking task.

Figure 3-18. Braking Process with hazard as stimulus

The experiment needs participants with different skill levels to find the different stages between less skilled and highest skills riders.

5. *Identification of braking patterns of riders related to performance:*

Identification of objective indicators that characterize performance (skill level) based on analysis of actions of high/low skill riders. The experiment needs experts performing the tests as demonstrator and reference guide.

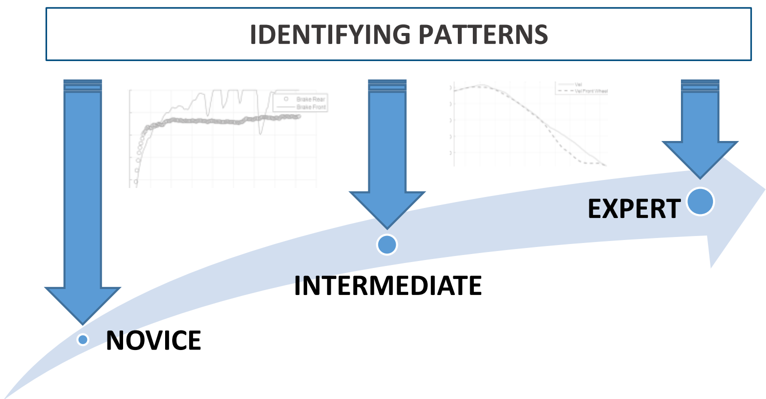


Figure 3-19. Identification of patterns different skills

The aim is understanding what low skill riders lack to perform as a higher skill rider (Figure 3-19). The different patterns of braking will feed a model to estimate the braking performance (measured in deceleration and braking distance) as a function of the interaction of the rider with the vehicle (e.g. maximum pressure, time to peak, maximum jerk, etc.).

6. Development of an interface tool to support training process with prescriptive feedback

As a demonstrator of the potential of the knowledge generated during the study, the model able to estimate the braking performance will be implemented in a tool to provide prescriptive feedback to the riders/instructors (Figure 3-20). This feedback will suggest specific targets to work in the improvement of the most significant parameters that will lead each rider to increase her/his braking competencies.

As commented in the subsection of *Overconfidence* from section 2.6.3, it is important for participants to recognise their own personal limits. By providing riders with objective feedback on such elements of their performance as disparity from target stopping distance, riders are aware of their own limitation, including highly skilled riders. Thus, our test treats defensive riding indirectly by highlighting the importance of safe minimum distance from the vehicle in front or the effect of speed in hazard perception.

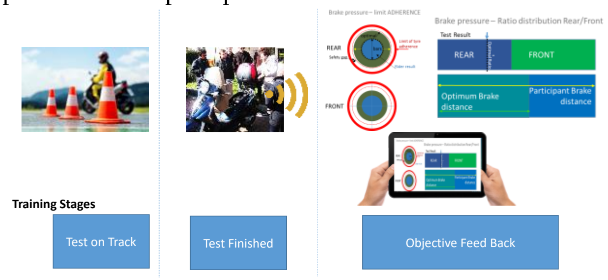


Figure 3-20. Diagram of Training stages with Objective Feedback

4. Emergency braking task – Material and Methods

4.1. Introduction

This chapter explains the methodology to run the test experimenting following the sequence of events that occurs in an emergency braking to avoid a crash (Figure 4-1), representing a test in real world controlled scenario.

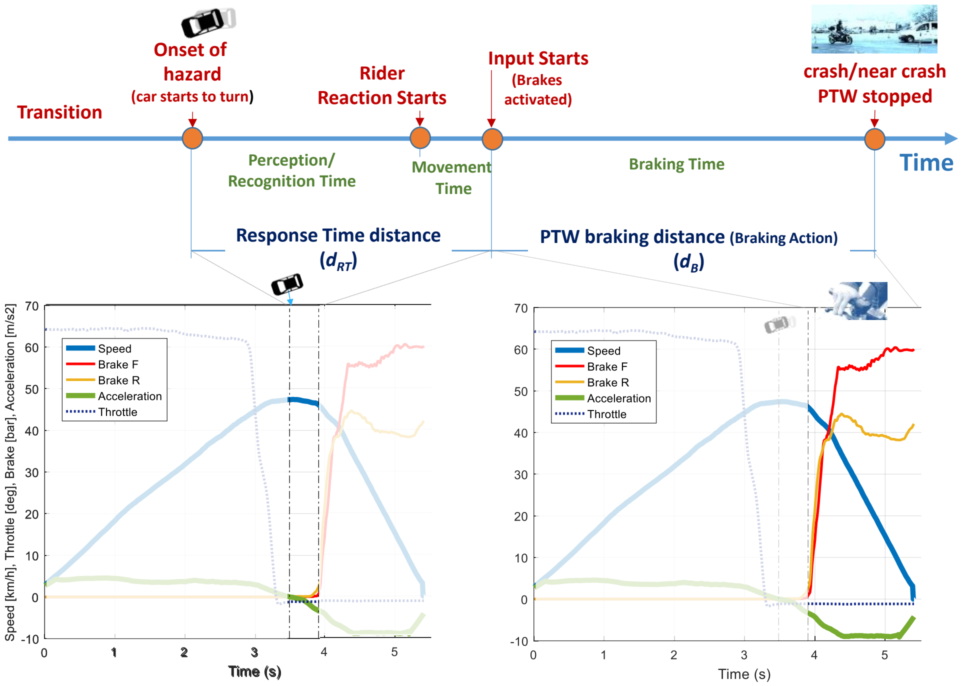


Figure 4-1. Course of events during emergency braking test

First, the material and procedure to run the tests will be presented. Secondly, the methods to measure and analyse the two different sequences of the emergency braking, i.e. response time to detect and recognize the hazard (car turning in front of the PTW) and braking action. After that, the two sequences of perception and action are joined to assess the competencies of the riders evaluating the total stopping distance. Finally, the data collected from the questionnaire to the participants including self-assessment is crossed with the results of the braking performance.

As additional analysis, the chapter presents two complementary experiments: study of comfort braking and hard braking; emergency braking test with a different type of PTW (high engine size motorcycle. The main objectives of the study presented in Chapters 4 and 5 are:

- Design a real-world controlled braking task
- Determine skill levels in braking performance
- Definition of key indicators that characterize performance (skill level) based on analysis of inputs from high/low skill riders

4.2. Material and Procedure

4.2.1. Ethical Clearance

The scenario designed is a unique realistic scenario for field experiments to assess riding behaviour in pseudo emergency scenario that carries a risk for the participants and needs a very well-defined protocol to ensure the desired level of safety. The protocol and procedure as already mentioned was approved by an Ethics Committee. Ethics clearance for data collection for this experiment was gained from Curtin University Human Research Ethics Committee on 29 July 2016 (Approval number: HRE2016-0164), and adhered to the tenets of the Declaration of Helsinki. All participants signed a consent form before starting with the experiment.

4.2.2. Equipment and data collection

Powered Two Wheeler

The PTW used for this test was a scooter-style Piaggio Beverly Tourer 300 (Figure 4-2), with the characteristics presented in (Table 4-1).

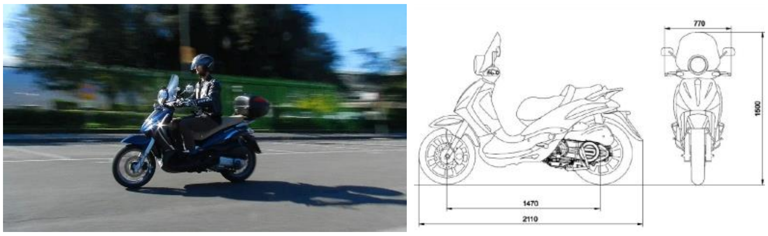


Figure 4-2. Beverly Tourer 300

Small-to-medium sized scooters (150-300 cm^3) represent the type of PTW most frequently sold in Italy. For this reason, the experimental PTW used was a Piaggio Beverly scooter with a 278 cm^3 capacity engine, automatic power transmission and standard brakes independently actuated (non-ABS, non-CBS) by two hand levers (right-front and left-rear).

Table 4-1. Characteristics of Scooter Beverly Tourer 300

Engine	
Number of Cylinders	1
Capacity (cc)	278
Type of engine	Cycle Otto 4 times
Valves per cylinder	4
Power	6.1 kW
Torque	23.0 Nm
Transmission	
Gear box type	CVT
Brake System	
Brake Front	Disco ϕ 300 mm
Brake Rear	Disco ϕ 240 mm

Dimensions	
Long	2110 mm
Large	770 mm
High min of the saddle	790 mm
Wheel-base	1470 mm
Mass dry	177kg
Capacity of Fuel	10l.
Pneumatic Front	110/70 R16
Pneumatic Rear	140/70 R16
Wheel Radius Front	0.280
Wheel Radius Rear	0.301

Instrumentation

The scooter was instrumented with an array of sensors (described below), video cameras and a data acquisition system to record the dynamics of the vehicle (Figure 4-3).

1. **Front Brake Pressure (bars)**
2. **Rear Brake Pressure (bars)**
3. **Speed (km/h)**
4. **Steering angle (deg)**
5. **Throttle position (deg)**
6. **Velocity time series (trial)**
7. **LED for synchronization**

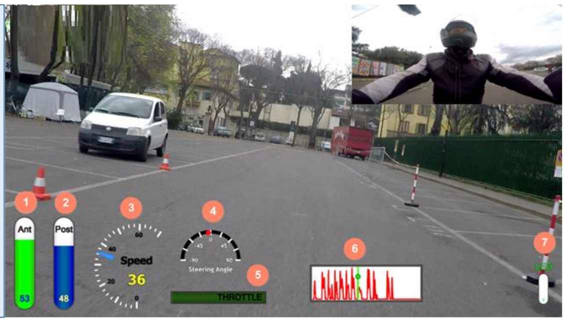


Figure 4-3. Representation of a videoed trial overlaid with signals from instrumented scooter.

Data Logger

The data acquisition unit used was a multichannel IMC model *BUSDAQ-2*. All sensors and devices were connected to this system. The system was triggered by the GPS signal which activates the data acquisition of the rest of the sensors at the same time to have them synchronized. All signals were sampled at a rate of 100 Hz. The data acquisition kit was placed in the back storage case (Figure 4-4).

Figure 4-4. - Back Case with the Data acquisition unit

Inertial Measurement Unit -3D accelerometers, gyrometers and GPS

An X-Sens inertial measurement unit (IMU) with an integrated GPS was used to record vehicle tri-axial acceleration, angles and rate of pitch, roll and yaw, plus position and longitudinal speed. The measurement dynamic range is +/-90° for Pitch and +/-180° for Roll/Yaw, the angular resolution is 0.05 °.

Brake activation and brake pressure

Brake usage was acquired redundantly from two different types of sensors. Braking intensity was acquired from pressure transducers attached to front and rear brake circuits separately. The transducers have a pressure range from 0 to 70 Bar and an accuracy of 0.5%. The front brake transducer was attached directly to the front calliper (Figure 4-5) while the rear brake transducer was attached to the rear brake fluid hose located under the scooter front cover. The intention of brake, or brake activation, was monitored from the touch of the brake levers acquired directly from the electrical wiring for each lever.

a) **b)**

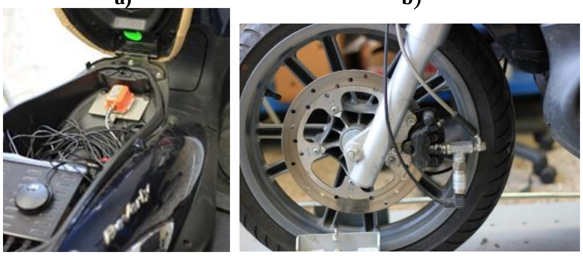


Figure 4-5. a) IMU placed on the longitudinal axis of the PTW placed below the saddle. b) Front brake Pressure transducer

Wheel speed

The wheel speed of each tire was measured independently with the use of phonic wheels. An ABS Wheel Speed active sensor was attached to the front shock absorber pillar and directed to the phonic wheel to read the front tire longitudinal speed. An ABS Wheel Speed active sensor was supported by a special bracket and attached to the rear shock absorber nut to read the rear tire speed. The sensor was powered directly from the scooter battery. Both sensor output signals were read by the data logger as incremental encoder signals.

Figure 4-6. Rear and Front Wheel Speed sensors with toothed disc

Steering angle and Throttle position

Steering angle and throttle position were measured using a rotational transducer and an angular sensor, respectively, both having a range of 120° and an accuracy of 0.3°. The steering

transducer was installed at the top of the steering wheel shaft, just below the cluster of the scooter. It is powered directly from the vehicle battery.
The throttle sensor was attached directly to the throttle shaft in the engine compartment. The sensor can operate from -40°C to 140°C to prevent heating damages due to the location of the throttle shaft.

Turn and Horn signal

The data logger received the turn and horn signal information directly from the scooter electric harness. When the turn or horn signal was activated, the electric signal was received by the data acquisition system.

Video Cameras

The timing and sources of visual information that guides emergency braking was examined using two high-speed video cameras (GoPro Hero5 Black) set at sampling rates of 100 fps to record environmental events and rider actions. The camera recording environmental events was placed on the front of the scooter to capture the exact onset of car turn initiation. The second camera was mounted facing the rider to record head movements, primarily. In addition, a tripod camera was placed in a side of the road to register the movements of the riders during the braking.

Synchronization between Video cameras and Data Logger

An LED with an external clock signal that was also connected to the data logger was mounted in the field of view for each camera to synchronization of the video data with the vehicle data recorded by the DAQ system.

Figure 4-7. High-speed video cameras and LED to synchronize Video and data logger

4.2.3. **Participants and Recruiting**

Thirteen subjects (11 male, 2 female), having various levels of expertise ranging from novice to expert were recruited by contacting riding schools and local racetracks, reaching out to groups through social media and posting flyers at the University of Florence. Candidates were screened via questionnaires to determine if they met the selection criteria including different skill level profiles. All subjects were required to have held a motorcycle license with no engine size limitation for more than 3 months, to have their own PTW and to ride regularly (minimum once per week).

Figure 4-8. Sample of subjects owning different types of PTWs and with different profiles on the Scooter instrumented

Demographic Descriptors

The participants completed pre-participation questionnaires that included demographic data. Data collected from the questionnaire also included information on motorcycle riding experience expressed in years and kilometers, self-characterization with respect to riding behaviour and information on training courses and track experience. The details of the consent form and questionnaire are presented in Annex1 and 2. Participants had a mean age of 32.2 years (SD=8.5), ranging between 24-47 years of age (see Table 4-2).

Table 4-2. Results of the demographic data collection and self-assessment

Demographics			
ID	Gender	Age	Experience (yrs)
1	M	27	10
2	F	41	2
3	M	24	7
4	M	26	10
5	M	23	7
6	M	47	31
7	M	39	19
8	F	29	11
9	M	40	21
10	M	24	8
11	M	24	6
12	M	30	13
13	M	45	-

4.2.4. Test Track Specifications

Data collection occurred in two asphalt parking lots located in metropolitan Florence (Figure 4-9). In each parking lot, a testing area measuring 90m x 20m was barricaded off using municipal traffic barriers to prevent the access of the pedestrian and vehicular traffic. A mock intersection was demarcated using existing curbing and lane markings of the parking lots, with the addition of traffic cones, in order to create an experimental scenario that closely mimicked a non-controlled intersection typical of the Florence road network.

a) b)

Figure 4-9. Parking Lot for Tests. Area 1 (a) and Area 2 (b)

4.2.5. Procedure – Emergency Test

The experiment required participants to visually perceive the movement and indicator signals of a car approaching the intersection from the opposite direction, and to carry out an appropriate response. In each trial the car approached the intersection at a nominal speed of 30 km/h. Figure 4-10 provides a schematic view of the mock intersection, orientated such that a car approaching from one end could either continue straight through the intersection or initiate a left turn.

a) b)

Figure 4-10. Trial with car initiating a Left Turn Across Path/Opposite Directions maneuver - Location 1 (a); Schematic view of the mock intersection (b).

The driver either continued straight through the intersection or initiated a left turn that would cross the path of the experimental scooter ridden by the participant. Both scenarios were performed either with or without turn signal activation prior to entering the intersection (see Figure 4-11). Each of the four conditions was repeated six times for a total of 24 nominal trials. The 24 trials were split in three blocks of eight. The four conditions were pseudo-randomized and counterbalanced so that for each trial the rider had an equal chance of having to respond appropriately to the car which either: turned left with no-indicator (NT: No indicator, Turn), turned after indicating (IT: Indicator, Turn), continued straight on with no indicator (NS: No indicator, Straight), or continued straight on despite indicating a left turn (IS: Indicator, Straight).

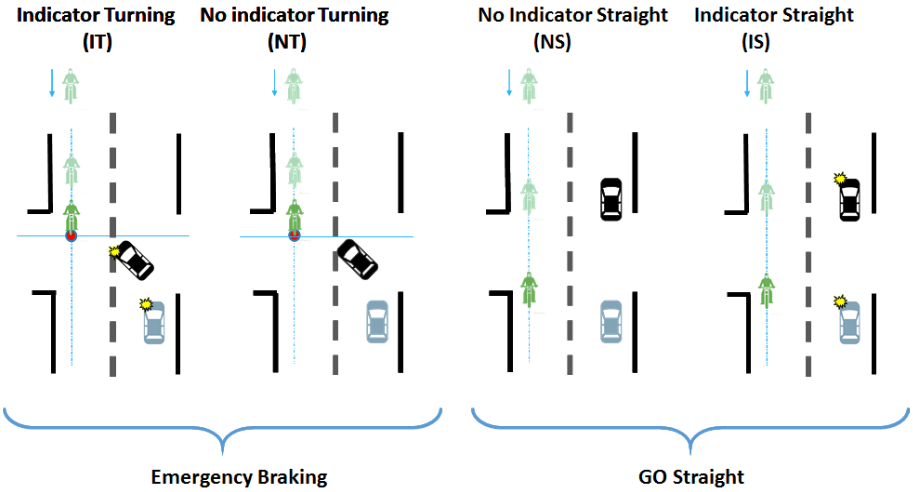


Figure 4-11. Representation of the four different scenarios of the test

The scenario of an opponent car initiating an unexpected left turn across the path of a PTW (Left Turn Across Path/Opposite Directions - LTAP/OD) was selected based on the criteria mentioned in section 3.4. To ensure the safety of the participant, the oncoming vehicle never completed the turn in front of the PTW, but stopped short of the center line in order to avoid any risk of collision with the rider (Figure 4-10.b) - this was strictly deemed by the protocol. All tests were carried out in daylight and in dry conditions. Paved asphalt was in good condition and the vehicle wore high grip tires to guarantee maximum friction. The car was driven by one investigator with a background in motor control, who practiced each maneuver during several pilot sessions as well as prior to each experimental session to ensure safe and consistent performance.

Familiarization phase

Before commencing the experimental trials, participants circulated through the mock intersection and practiced braking for a minimum of 10 minutes in order to familiarize themselves with both the experimental scooter and the testing environment[4]. Following this self-guided warmup period, participants were provided with seven practice trials that demonstrated the four conditions. For the first four practice trials, participants were informed of the maneuver that the car would execute and whether the turn signal would be activated prior to the trial. In the last three trials participants performed practice trials exactly as they

[4] Prior to familiarization, participants were instrumented with wireless electromyography sensors incorporating 9 DOF inertial measurement units (triple-axis accelerometer, triple-axis gyro, triple-axis magnetometer).

would perform them for the experiment, i.e. without foreknowledge of the car's manoeuvre or indications.

Tests Procedure

Figure 4-12. Scenography of the test with emergency braking from the video cameras. Car turning Case

For both the practice and experimental trials the vehicles started from stationary positions at opposite ends of the experimental area. On a visual 'go' signal both vehicles began moving towards the intersection. The familiarization phase was also used to refine the synchronization of PTW and car to get to the intersection simultaneously in a consistent way. If the researcher perceived that the participant was arriving too early, then the researcher instructed to start with a corresponding delay after the ‘go’ signal. Participants were instructed to reach speeds of 40–55 km/h (11.1 - 15.3 m/s) on approach to the intersection and respond according to whether the car turned or continued straight on. The travelling speed was selected based on the conclusions of section 3.4.

Specifically, participants were instructed to brake as quickly and as hard as possible while maintaining balance and control, as in an emergency situation, only if and as soon as they perceived that the car would turn across their path, regardless of whether the driver used the turn indicator to turn or not. On the contrary, participants were instructed to continue through the intersection if they perceived that the car would continue straight on, again regardless of whether the driver indicated the turn (see Figure 4-12). After each trial both vehicles returned to their initial positions and awaited the next ‘go’ signal.

Riders were instructed further that they must brake to avoid collision with the vehicle and must not swerve (any trials for which this occurred were discarded and rerun at the end without participants’ knowledge). The procedure was designed to eliminate the decision making process in the response time.

During the tests, if the rider executed an incorrect maneuver according to the predetermined trial order, or the synchronization between the vehicles at the intersection did not permit a realistic braking response, the trial was repeated after the conclusion of all 3 sets of 8 trials, with a maximum of 4 additional repeated trials.

4.3. Perception Skills: Response Time

4.3.1.**Background**

In real world the response time depends on the rider’s ability to perceive and recognize the hazard, decide on the appropriate action to take and react to the stimulus. In the task defined in this study the rider is aware about the possibility of a hazard and the decision making process has been removed since the participant has the instruction to brake hard as soon as he/she recognizes the onset of the hazard stimulus. Nevertheless, the task defined in thesis adds an innovative perspective, the majority of previous studies in this field have assessed the perception of the drivers without integrating the workload of the control of the vehicle (e.g., using PC or static simulator screen).

The few studies that integrated perception and action used a static two dimensions *hazard* to detect, such as panels with lights on test track (Davoodi et al., 2012; Kawakoshi et al., 2014) or lights on the PTW board (Ecker, Wassermann, Ruspekhofer, et al., 2001). The proposed test represents a novel realistic scenario with a dynamic hazard, randomization of the emergency cases and high workload requiring to control the vehicle at the same time that the environment is scanned.

A limited number of papers focused on the PTW riders reactions related to braking. In (Davoodi, Hamid, Arintono, Muniandy, & Faezi, 2011) the Perception-Response Time (PRT) of riders was experimentally determined in case of an expected braking event of a leading object. In Davoodi et al. (2012) a similar study was performed, always in controlled conditions, to determine the PRT of riders for expected and unexpected objects appearing on their path.

Avoiding collisions whilst navigating a busy intersection on a PTW requires the rider to track and anticipate the trajectory of other vehicles with precise temporal and spatial accuracy. Consequently, collision avoidance is analogous to other interceptive timing skills. Chronometric analysis is one of the key methods used to study the coordination of the visual stimulus with a motor response. This method involves the use of one of more high-speed cameras to synchronously record a performer's (e.g., a rider) response (brake activation) to visual cues arising from the movement of the target object (e.g., a moving vehicle). Frame-by-frame analysis is then used to determine the timing of the rider's actions relative to critical events in the movement of the stimulus (following methodology of Müller, Brenton, & Rosalie (2015)). To measure the response time of the riders two instants from the sequence of the evasive manoeuver were detected (Figure 4-13): a) onset of the car turning; b) starting action of the brakes.

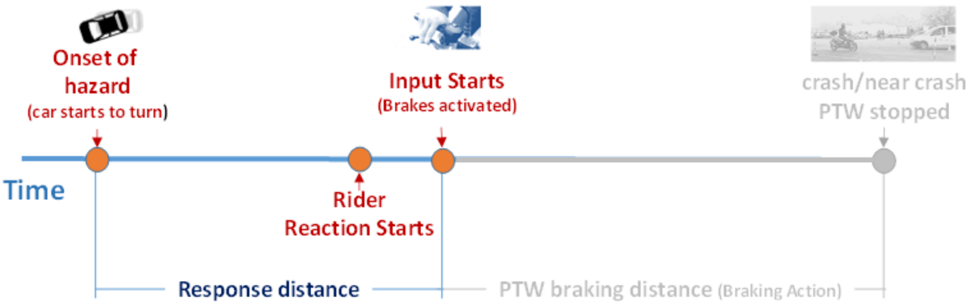


Figure 4-13. Sequence corresponding to braking response time of the test

4.3.2. **Identification of the Onset of the Hazard: car turning**

The identification of the onset of the stimulus was measured with video-camera placed on the front PTW. The video analysis has been done with the software Render Race®, used as a tool to synchronize the multiple sensors input from the PTW with the videos registered. This software integrates the signals from the data logger in the video, so the synchronization of video and data logger was done integrating LED level from the timer (ON/OFF) in the image from the video. The video was synchronized when a blue light or blue tonality appeared at the same time that the signal from the data logger clock that activates the LED (Figure 4-14).

a) **b)**

Figure 4-14. LED signal and Video synchronization: a) out of sync; b) synchronized

The software works with a frame rate of 33 milliseconds (30fps). Although this limitation was considered initially as a setback, after recording the videos it was decided to register with 60 fps as the best solution quality/framerate since the quality of the videos with 100fps lost quality and stabilization of the image. The video analysis of the tests has shown that 33 milliseconds is enough to do the analysis since it is hardly possible to find difference in the image in shorter periods.

Stimulus to detect the onset

The hazard of the experiment was represented as a car changing its straight trajectory to cross in front of the rider's path. This dynamic condition makes that there are different cues that have to be considered (not as tests with a stop light) to determine the onset of the hazard. The five visual indicators used in the analysis are the following:

A) Driver's hand movement on the steering wheel

B1) Movement of the front internal wheel to turn

B2) Movement of the front external wheel

C) Dimensions of the lateral side of the car

D) Position of the car referenced by road intersection

Figure 4-15. Visual stimulus considered to determine the onset of the car turning

The time of the onset of the hazard was registered considering all five indicators, since depending of the conditions of light or the distance some indicators were easier to detect the onset than others. In the tests that the onset measure was considered not reliable because of the limitations mentioned, the test was not considered for the analysis. For this reason some of the riders have less than 12 values of response time.

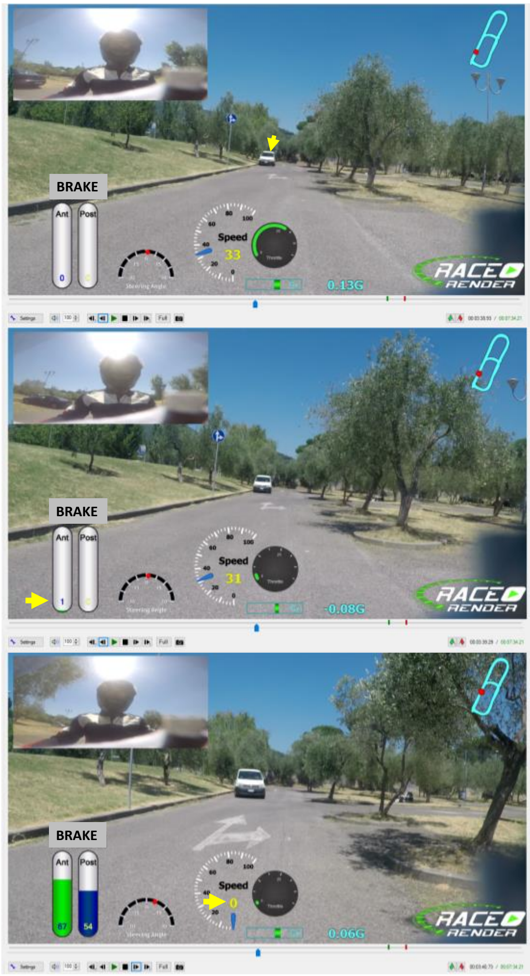


Figure 4-16. Sequence of the emergency braking: 1) Onset of hazard; 2) Start to brake; 3) Stopped

4.3.3. Identification of the Start of a deliberate action of Braking

The start of brake activation was defined based on the values from the pressure sensor of brakes (the earlier of either front or rear wheel). It was found that often the participants, in preventive action, placed the fingers on the brake lever when bringing the intersection closer. Electric signal from the brake light was excluded as valid signal after verifying that the light was activated at the contact with the levers without actually applying pressure on the brakes, which gave false positives when the rider was preparing the braking just before the full braking action (Figure 4-17).

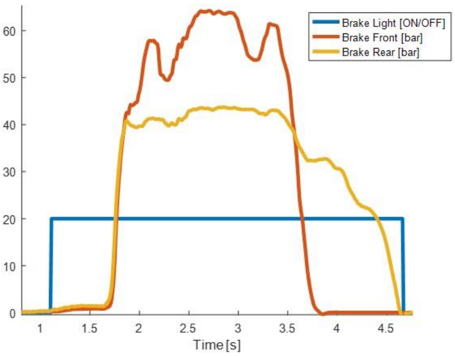


Figure 4-17. Representation of the Brake signals. Case with rider preparing the brake action

The start of the action was not based on a threshold of the brake pressure since a few riders sometimes, as a matter of preventive action, applied a very soft pressure on the brakes that they kept until applying the actual emergency braking response action (Figure 4-18) or until releasing the levers if the car was going straight. The most reliable and consistent parameter to determine the start of the brake action was the gradient of pressure. The threshold based on the gradient of pressure (for both brakes) was also computed to determine when the riders where performing an "abnormal braking". According to the instructions received by the riders, "abnormal braking" was defined as the braking action in the absence of stimulus (i.e. when car was going straight instead of turning in front of the rider). To avoid false negatives, the gradient threshold was determined by the brake response of the most novice rider, who was the one with the lowest gradient in the braking trials (IT, NT).

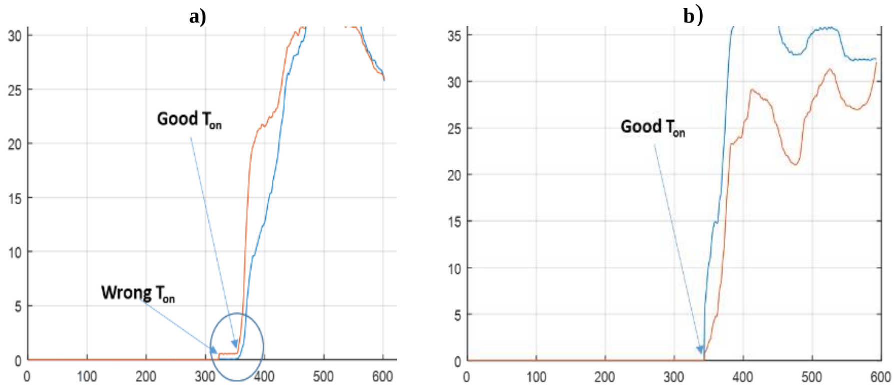


Figure 4-18. Example of rear and front brake signal during braking test: a) starting braking as prevention but not knowing if car is turning; b) starting braking only when car is turning.

Based on this info, for this research, the following criteria were used to define the start of the deliberate action of braking:

- the gradient of braking pressure rate trigger (higher than 60bar/s);
- the time above the threshold necessary to consider deliberate reaction (40ms).

A script with Matlab code was developed to detect the start of the brake and calculate the response time per trial based on the onset of the car turning measured as defined in section 4.3.2 above (Figure 4-19).

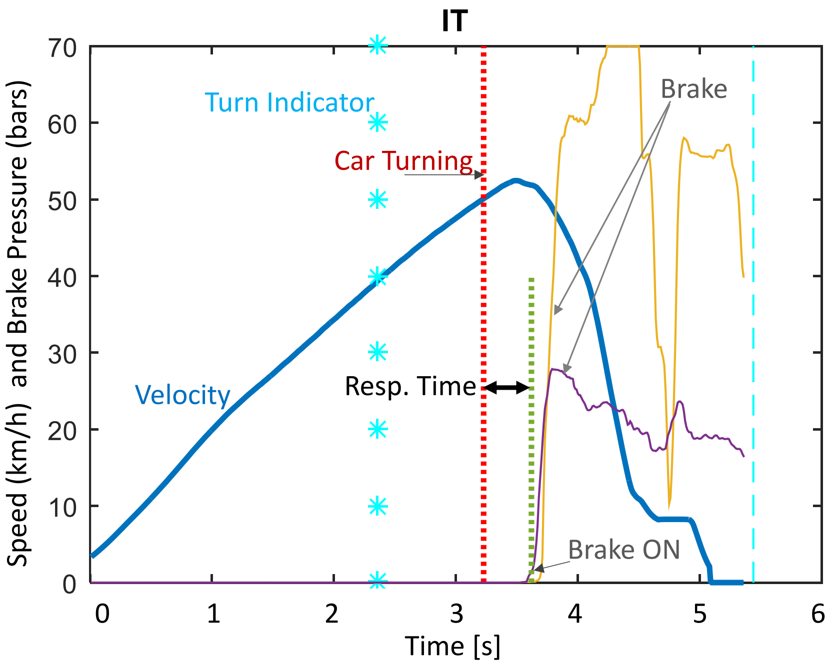


Figure 4-19. Example of measure of response time for scenario IT. Vertical Lines that define the Response Time are the onset of the Car Turning and the Start to brake instant.

Verifications on the reliability of the participants

The tests where the car was going straight (GS and IS) were analysed in order to check if the riders were systematically starting to brake when bringing the intersection closer or on the contrary followed the instruction of braking only for a full stop braking when they perceived the car turning. In the analysis it was considered the possibility of an instinctive *unwanted braking* action in the first trials when participants watched the turn indicator ON as a normal stage of the procedure learning. Figure 4-20 shows an example where the rider started to brake before the intersection in a IS scenario (turn indicator and car straight).

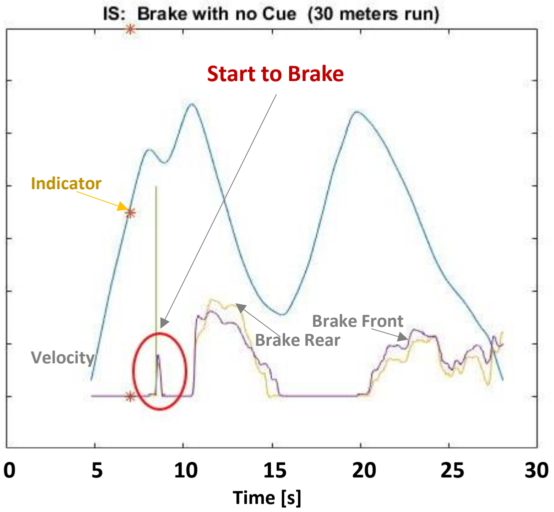


Figure 4-20. Indicator Straight scenario with instinctive (not instructed/unwanted) braking action of the rider after activation of the turning indicator '*'.

4.3.4. Response Time analysis and identification of levels of competencies

To evaluate differences between subjects as a measure of skill, the means for response time of the valid trials are first calculated for each subject when they were requested to brake (NT and IT). To test the hypothesis that response time profile provides an objective measure of performance (and thus skill), ANOVA with subject as the factor was done, followed by a post-hoc Tukey analysis to determine groups that were significantly different from each other. Finally the intra-rater variability was calculated to measure the consistency of investigator that identified the onset of the car turning by video analysis.

4.4. Control Skills: Braking Performance

4.4.1. Optimal Braking

When the brakes are applied, the brake pads press against the disks. This generates frictional forces, the level of which can be controlled by the rider by the pressure applied to the brake levers/pedal. Optimum braking is considered when both wheels have the same adherence with the road surface, offering better stabilization. The optimum braking, i.e. how to distribute the force in rear and front brake, is related to different factors. The most important are the wheelbase, center of mass (CoM) and friction coefficient of the road. To estimate the optimal braking of the PTW of the tests it was defined a simple model based on (Cossalter et al., 2004) that considers steady state conditions with rigid suspensions and, thus, a constant height of the CoM. The model has estimated some parameters of the PTW including (a + b) and CoM height (h) (Figure 4-21) and 70kg as the mass of the rider. This simplification was introduced to reduce the number of model variables focusing on rider-vehicle interaction and training activities.

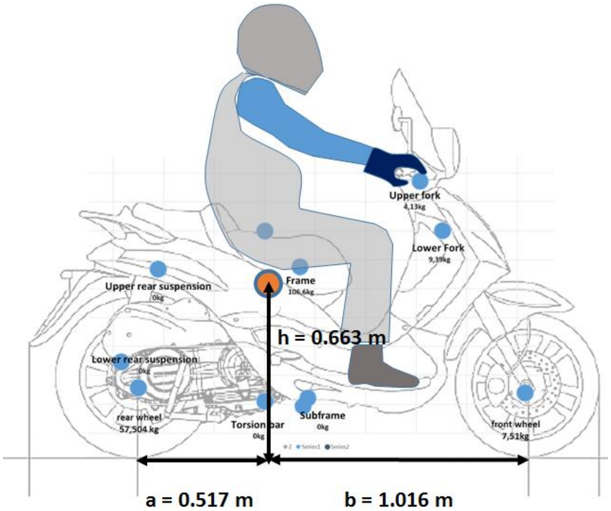


Figure 4-21. Center of Mass (CoM) of scooter-type PTW of the experiments

As it can be seen in Figure 4-22, deceleration of 1g can be obtained with different distributions of the braking force (p= [0, 0.1, 0.2]), where p is percentage of total force distribution of rear brake. In order to achieve optimal braking, the brake must present similar normalized braking forces for rear and front tires. This way the friction limit of the tires are as far as possible from both tires, i.e. braking forces are well balanced (Cossalter et al., 2004). Optimal braking repartition corresponds to the diagonal of the friction rectangle. As deceleration increases, *p* (percentage of total force distribution of rear brake) decreases, which means that braking becomes more predominant with front brake (for µ =1 close to p=0.2, around 20% rear 80% front). The model also considers the point where the transfer of load makes that the rear wheel lifts (stoppie) to know if there is risk during the tests with the participants. Based on the simplified model done, where the deceleration must be limited by the expression $decel < g\frac{b}{h}$, the PTW from this test would reach this limit with a friction coefficient $\mu_{stoppie}$ of 1.16 (see Figure 4-22). Thus, considering maximum friction coefficient of μ_{max} =1 on a dry and clean asphalt, the front wheel will skid before without risk of stoppie ($\mu_{max} < \mu_{stoppie}$), after applying front brake at maximum level. In Figure 4-22 each line associated at a different value of p cuts with the lines of decelerations 1g, 0.9g and 0.5g. As the figure shows, the optimal distribution of braking forces must be adjusted step by step, in accordance with deceleration.

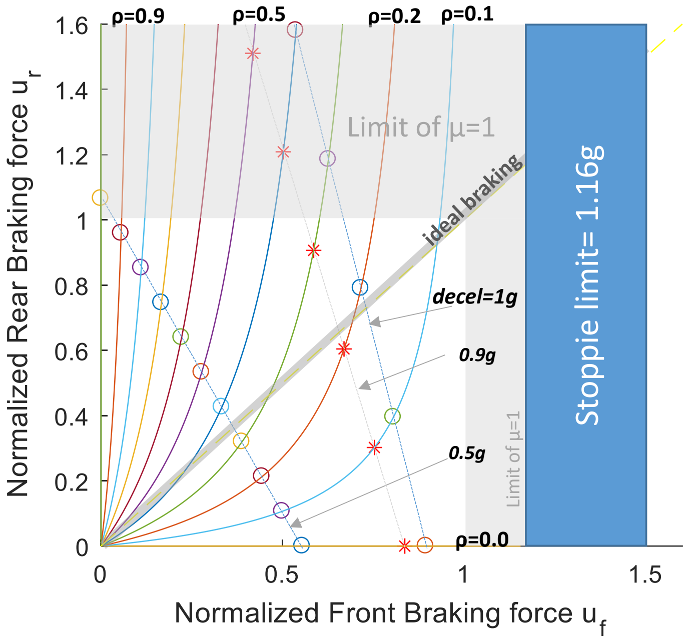


Figure 4-22. Distribution of the braking force (mass= (187kg+70kg), 'a', 'b' and 'h' of the model based on the geometry and CoM of Figure 4-21)

The estimation of the braking force based on the pressure of the brake callipers has been done to have a reference of the ideal braking with the model of PTW of our experiments (Figure 4-23). For this calculus the following data from the PTW has been considered:

- friction coefficient between braking pad and disc: 0.38
- diameter of the piston: 0.028m
- mean radius of the braking surface of the disc: 0.220m
- moment of inertia of the wheels (kg·m^2): front(0.7) and rear (0.8)
- radius of the wheel (m): front (0.280) and rear (0.301)
- braking traction coefficient for tires: front (D_f=0.9) and rear (D_r=0.9)

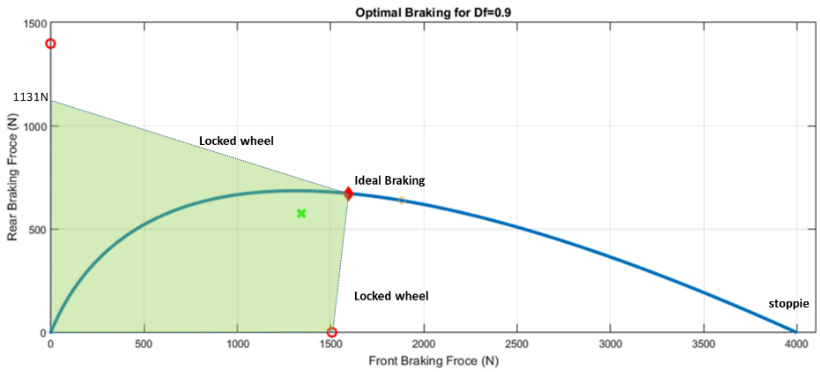


Figure 4-23. Friction-optimal Brake Force Distribution (BFD). Df/Dr=0.9. // Df= μ(λ_{max}) (friction coefficient). Green area: admissible braking maneuvers without locking wheels

Based on the work of Corno et al. (Corno et al., 2008) following key points are defined in the braking action:

- the wheel-lock problem;
- the loss of contact of the rear wheel
- the effect of aerodynamics on the loss of contact of the rear wheel;
- the best torque modulation strategy at the beginning of the braking maneuver;

4.4.2. Data Conditioning

The spectrum analysis of the accelerations from IMU indicated dominant frequencies in the multiples of 14Hz (frequencies of 14Hz, 28Hz and 42Hz Figure 4-24). This noise was due to the noisy nature of the accelerometers and gyroscopes due to the engine vibration. Thus, accelerations signals were low-pass filtered using a cut frequency of 14Hz. The spectrum analysis of the signals from brake pressure and wheel-speed did not find any dominant frequency to filter. However, since the differential of these signals is required to compute the gradient of brake pressure and the angular acceleration of the wheels, it was necessary to reduce the noise by smoothing. Brake pressure and wheel-speed were smoothed using Gaussian function with a window of 200 milliseconds. The speed of the PTW was registered with three different measures, front wheel speed, rear wheel speed, IMU speed.

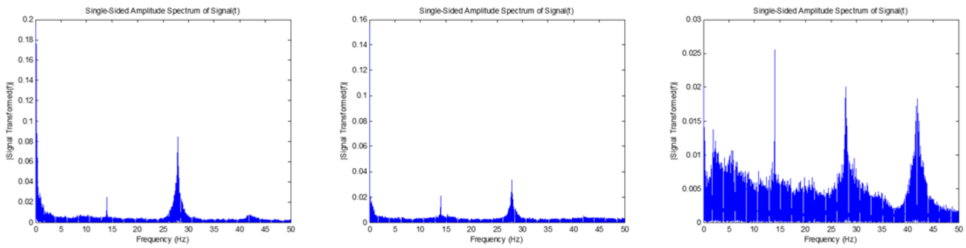


Figure 4-24. Spectrum Analysis of the 3axis accelerations of IMU: from left to right (X, Y, Z)

The start of the braking period was defined as the time at which the pressure applied to either the front or rear brake exceeded a threshold of 2 bars while longitudinal acceleration was negative. We identified 2 bars as the pressure indicating when the rider was using the brakes in an intended, purposeful manner to effect deceleration braking (in contrast to lower pressures that did not effectively reduce wheel speed). The trigger selected starts before than the one for measuring the response time. Because of different effects in the suspensions dynamic, using a trigger of gradient of braking > 60bar/s would mean that the riders that started to use brakes initially as a preventive way before get that trigger (with gradient values lower than 60bars/s) would have an advantage compared to the riders that followed strictly the instructions of the tests. Thus, in order to set a fair braking performance comparison between riders it was decided to use 2 bars of braking pressure as the trigger of the braking action. The cases where it was detected that the time between the physical action of braking (pressure higher than 2 bars) and the deliberate action of braking because of the perception of the car turning (brake gradient >60bar/s) was higher than 0.4s were removed from the study since it was considered that the action of braking of the rider was not fitting with the procedure of the study. The end of the braking event was defined as the time at which speed dropped lower than 2 km/h.

4.4.3. **Braking performance indicators: Effective and Maximum Deceleration**

This section analyses the PTW deceleration during 157 emergency braking trials in which the car actually began a turn in front of the rider, performed by 13 riders of varying skill levels.

Deceleration for the entire braking period was measured using both the IMU speed and the wheel speed. The longitudinal acceleration (a_{long}) was computed from the differential of the speed data collected (100Hz) from the wheel velocities and IMU during deceleration manoeuver (1).

$$a_{long}(t) = \frac{d}{dt} v(t) \tag{1}$$

In discrete form (1) becomes

$$a_{long}[n] = \frac{v_n - v_{n-1}}{T_s} \;\Rightarrow\; dec_{long}[n] = -a_{long}[n] \tag{2}$$

Effective deceleration (defined below) and maximum deceleration values were firstly used to evaluate performance and for comparisons across trials and subjects.

Effective deceleration

The effective deceleration was not calculated from the average of the time series of the deceleration during the braking period, since it would assume that all riders perform the braking manoeuver at constant deceleration. Ecker et al. (Ecker, Wassermann, Ruspekhofer, et al., 2001) found that increasing deceleration was the most frequent response, and that in some cases the deceleration was decreasing after the fast first peak. Thus, this effective deceleration would not represent faithfully the braking distance.

This parameter selected (effective deceleration) provides an accurate assessment of the rider's actual braking performance in a given trial because it relates directly to total braking distance. Thus, for computing effective deceleration it is required to compute first the braking distance. The braking distance (d_b) was measured by integrating the PTW speed time series *v(t):*

$$d_B = \int_{Brake_{ini}}^{Stop_{PTW}} v\,dt \quad \text{, in discrete form becomes} \quad d_B = \sum_{j=1}^{n-1} \frac{v_j}{T_s} \tag{3)(4}$$

where n is the number of samples and T_s the sample rate (0.01 seconds).

The effective deceleration ($dec_{effective}$) was computed using the braking distance (d_B) and the difference between final velocity at stop ($v_f \approx 2$ km/h) and velocity at braking initiation (v_i) (equation 5). This measure provides an accurate assessment of the rider's actual braking performance in a given trial because it relates directly to total braking distance.

$$dec_{effective} = -\frac{(v_f{}^2 - v_i{}^2)}{2 * d_B} \tag{5}$$

Maximum deceleration

The dec_{max} was computed as the 95th percentile of the longitudinal deceleration (dec_{long}) time series as a more robust value than the absolute maximum deceleration (which could be just a transient peak).

4.4.4. Time Series Analysis – Functional Data Analysis

Statistics such as standard deviation, coefficient of variation, and range assume little association between discrete measurements taken at different points in the performance timeline. Functional Data Analysis (FDA) can be used to observe drivers' performance over time. Time-series analysis allows to plot key kinematic variables examining the structure of movement variability in a given performance rather than simply the magnitude of outcome variability. The work of Ramsay & Dalzell (1991) described and discussed the theoretical basis of FDA and its differences and advantages with respect to multivariate data analysis.

Functional principal component analysis (FPCA) was applied to the accelerations obtained from the braking tests of 8 participants of different level skills and was carried out by using the free library FDA for MATLAB available at http://www.psych.mcgill.ca/misc/fda/. The full procedure to compute FPCA is described by Epifanio et al. (Epifanio, Ávila, Page, & Atienza, 2008). Analogous to multivariate principal component analysis, FPCA examines the dominant modes of variations in a group of functional data. This study follows similar approach of Wang (2015) that explored different driving patterns from a large group of repeated time series measurements of speed.

4.5. Braking performance vs Years of experience and Skill self-assessment

Answers from the riders' survey were compared to the braking performance to know whether braking skills correlate with riders' experience and/or with self-assessments of specific riding skills. Self-assessment skills were divided in four types: braking skills, hazard perception skills, overall skills and overall safety (Figure 4-25).

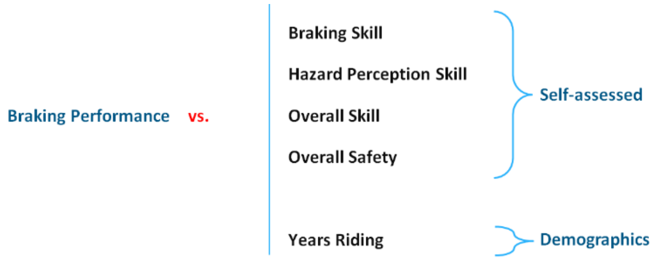


Figure 4-25. Diagram of the data analysed for correlation

Spearman's rho tests were performed to test the hypothesis of a relationship between years of experience, self-assessed measures of skill and mean effective deceleration. The 95% confidence intervals for the correlations were calculated by transforming the correlation values to Fisher Z statistics, then calculating the standard error and 95 % confidence interval of the Z scores before transforming the upper and lower bounds for the Z tests back to the correlation coefficients.

4.6. Model of braking performance. Definition of key patterns

Linear regression models are calculated to predict/describe braking deceleration and distance based on descriptive parameters of the braking action with the motorcycle. This analysis has two goals. First, to investigate which measures are valuable for analysing braking and offering a better general understanding of the braking manoeuvre itself. Secondly, to have a model to provide feedback with the estimation of the improvement of the riders in case they modify one of the descriptive parameters.

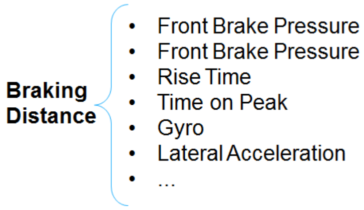


Figure 4-26. Model to predict Performance

The selection of the independent variables for the model is based on parameters related to the direct action of the riders with the brakes (Figure 4-26). The purpose is to have a model easy to understand to provide prescriptive feedback to improve the braking performance modifying the parameters of the model.

This information will help to understand in terms of specific parameters what make expert riders good in comparison with low skilled riders. This model is used with a tool defined in Chapter 6 that may predict the progress of the less skilled riders by improving independently one of the key parameters.

Variable predicted: Braking distance

The dependent variable of the model is the braking distance, so the first step is to standardize the values of the braking distance of the tests. The travelling speed of the riders in the pre-braking instant were considered 50 km/h. The standardized braking distance '$dist_{std}$' is calculated with the effective deceleration '$a_{effective}$' of the tests - equation (6) – and the final velocity 'Vf' as 0km/h following the equation:

$$dist_{std} = \frac{(Vf^2 - (50km/h)^2)}{2 * a_{effective}} \tag{6}$$

Variables predictors

A set of braking parameters from experimental data was calculated in addition to the maximum and effective decelerations, including data from throttle, steering, IMU, wheel-speeds and brake pressure. After a principal component analysis (PCA) a set of variables was pre-selected to characterize the braking deceleration (Table 4-3)

Table 4-3. Parameters used for the regression model with braking distance as dependent variable

Front Brake Max	Percentile 90 of Brake pressure on front wheel (bars)
Rear Brake Max	Percentile 90 of Brake pressure on rear wheel (bars)
P_Ratio_Brake	Ratio of Rear Brake Max: *Rear Brake Max /(Rear Brake Max + Front Brake Max)*
Time to peak	Time to reach the first peak of deceleration (s)
Time on peak	Time over the Percentile 75 of deceleration (s)
slip factor	Maximum value of front wheel slip (%) – 100% = locked wheel
lock front	Time with slip factor in front wheel = 1
lock_rear	Time with slip factor in rear wheel = 1
skid_front_time	Time with slip factor in front wheel >0 and <1

Max Brake Pressure

The front and rear wheel brake action was computed from the time series of the braking pressure. The Maximum Brake values were calculated as the 90 percentile of the time series data.

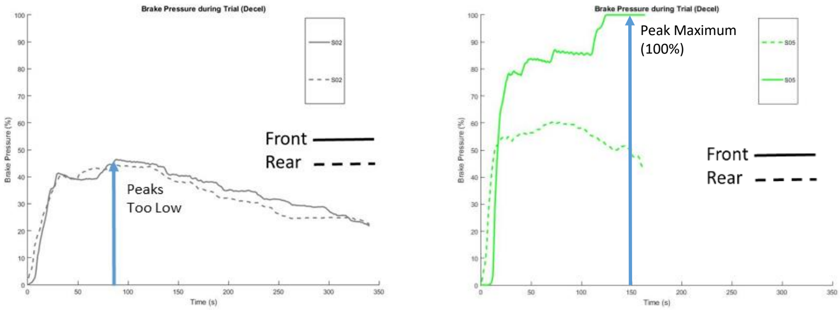


Figure 4-27. Examples of maximum brake pressure for 2 different riders

Time to peak

The time to get the first peak of the deceleration with a value higher than 2.5m/s^2 ('time to peak') measured how fast the riders apply the brakes (rise time), see Figure 4-28. The deceleration was previously smoothed to avoid 'false' peaks. The value of 2.5m/s^2 was decided to include the first peaks of the lowest deceleration tests.

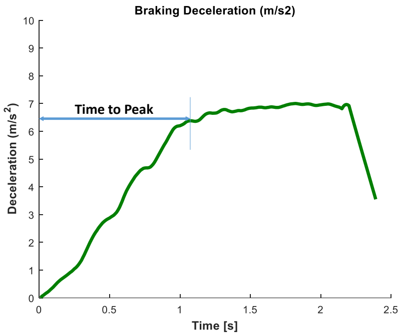


Figure 4-28. Representation of parameter Time to Peak

Time on Peak

The 'time on peak' is the parameter that measures the first period of time that the deceleration is higher than a 75% of the peak deceleration (Figure 4-29). This parameter is related to the time the rider takes to release the brakes once it has close to the top deceleration.

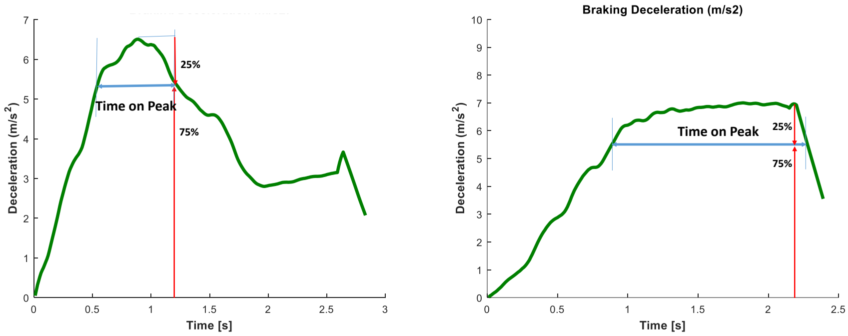


Figure 4-29. Representation of parameter Time on Peak

Longitudinal Slip Factor-

Wheel slip was computed using the speed from the IMU (V_{IMU}) and the front wheel speed (V_{wheel}), following the equation (7):

$$\boldsymbol{slip\ factor} = \frac{\boldsymbol{V_{IMU} - V_{wheel}}}{\boldsymbol{V_{IMU}}} \tag{7}$$

Figure 4-30 shows an example of the measure registered of slip factor for a braking trial with a locked front wheel.

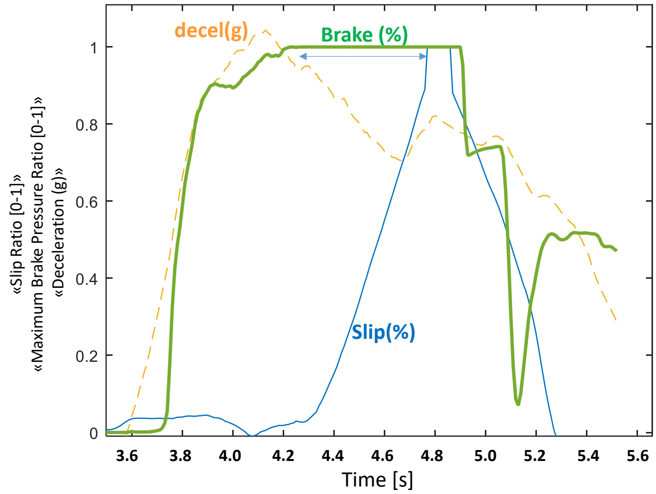


Figure 4-30. Example of locked wheel case with slip factor 100%

Skidding and Locked time

Rear and Front wheel were considered to start to skid when 'slip factor' > '0' and when the speed from the wheel sensors was 4km/h lower than the speed from IMU. Skid time is the parameter that measures the time that the wheels (rear or front) are skidding without being locked ('0' < *slip factor* < '1'). When the speed from the wheel sensors was zero and the velocity from the IMU was higher than 4km/h it was considered that the wheel was locked. The time corresponding to skidding and locked wheel states were computed. Figure 4-31 shows an example of a trial where the speed from the rear and front wheels become lower than the IMU speed as a consequence of the wheels locked-up.

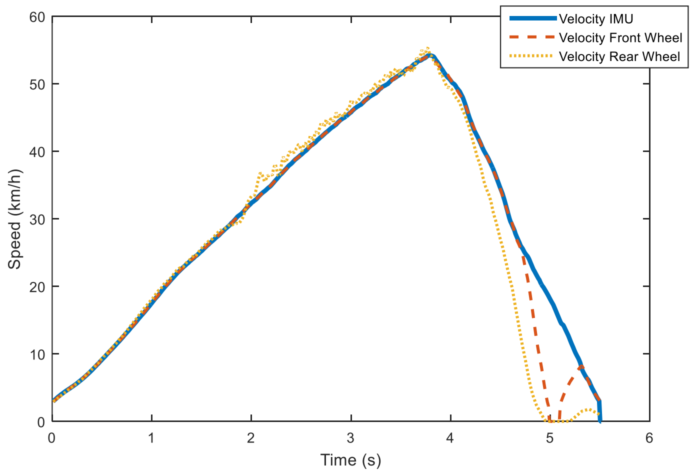


Figure 4-31. Example of trial with rear wheel and front wheel locked

Figure 4-32 shows and example of a typical case where the rear wheel is locked after applying a constant brake pressure (around 48 bars) for 0.25 seconds.

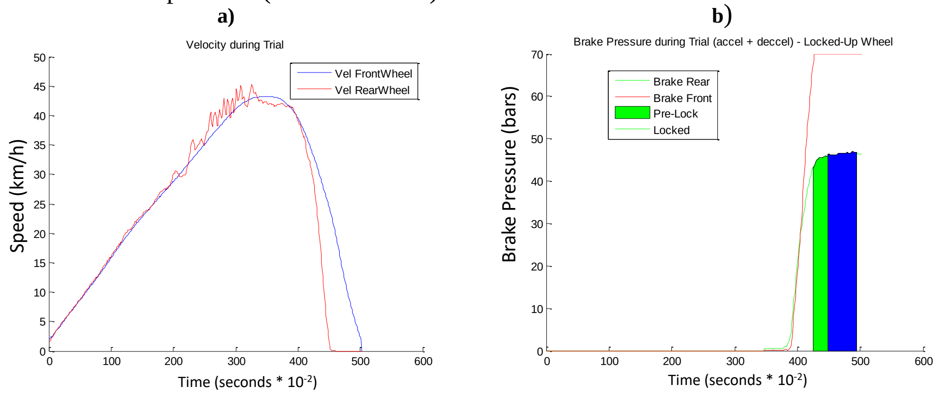


Figure 4-32. a) Example of trial with rear wheel skidding and locked; b) Braking pressure of Front and Rear brakes of the trial with rear wheel skidding (green area) and locked (blue area)

4.7. Total stopping distance: Response Time + Brake Action

The total stopping distance was measured as the sum of the response time distance and the braking distance of the emergency tests (Figure 4-33). The distances is standardized using 50km/h as the travelling speed before braking and calculating the braking distance with the deceleration calculated as it was done to compute the regression model. The two distances are calculated as follows:

- Response time distance is the distance travelled with a speed of 50km/h during the time calculated as response time.
- Braking distance computed for an initial speed of 50km/h and the deceleration effective calculated.

Figure 4-33. Representation of Total Stopping distance during the braking task.

A representation of the braking distance, response time distance and overall distance will help to understand the different profiles of riders, since they can achieve same stopping distances with different skills (perception or control).

4.8. Loss Stability Indicator

An indicator to predict the loss of stability of the rider was defined using the parameters related to signals collected steering angle; roll angle and lateral acceleration and front wheel slip factor. The process was the following:

a) Identification by video analysis and notes in the field based on observations of the tests where the rider was close to lose the control.
b) Definition of the parameters that characterize the behaviour of the braking event that predict loss of control.
c) Selection of a subsample to train the binomial model
d) Definition of the categories based on the percentage predicted by the model.

This indicator is the index of probability of losing control, using as input all the tests, including those where (based on observations) it was considered that the riders were close to a loss of control. After reviewing the registered videos of the emergency braking tests by observation, the trials were classified as '0' if it was considered that the rider had full-control or, on the contrary, as '1' in case there were signs of losing the control (Figure 4-34).

Figure 4-34. Example of Loss of Control after locking front wheel

This indicator may be used to check whether riders have done a safe braking manoeuver or on the contrary are trying to perform beyond the limits of their control skills. Giovannini et al. (Giovannini, Baldanzini, & Pierini, 2014) defined safe braking as a manoeuvre "*that allows the vehicle to stop in upright position, safely, without oscillations (or with small oscillations), and with limited effort for the rider to control the steering bar*". Loss of control may be limited to forgoing some safe behaviours and not necessarily to total loss of control.

After a principal component analysis (PCA) of different parameters derived from the four signals cited, a logistic binary regression model has been developed to predict the probability of losing control using the '0' and '1' assigned to the trials by observation.

Based on the probability calculated, the model will assign and indicator with three possible control levels: full control, limit of control and loss of control. Thus, if the indicator of stability is in the range of full control, the instructor may decide to push the rider to improve their performance based on the key indicators defined previously. Otherwise the instructor will suggest practicing more until the braking performance is assumed as part of the comfort area.

4.9. Comparison between *Hard braking* test and *Emergency task*

Following the emergency braking trials, participants performed 3 hard braking manoeuvers with no opponent vehicle. These additional trials were compared to the last 3 braking trials of the emergency braking test to assess whether the rider braking performance differed when initiation was self-determined compared to in response to a hazard stimulus (Figure 4-35). The participants were instructed to reach 50km/h and brake as hard as possible on arriving at a virtual line indicated by traffic cones placed on either side of the lane. The line was used merely as a reference and participants were not constrained to brake at that exact point since the braking distance was measured from the initial application of the brakes until the PTW stopped. These hard braking tests were performed by 11 of the 13 participants.

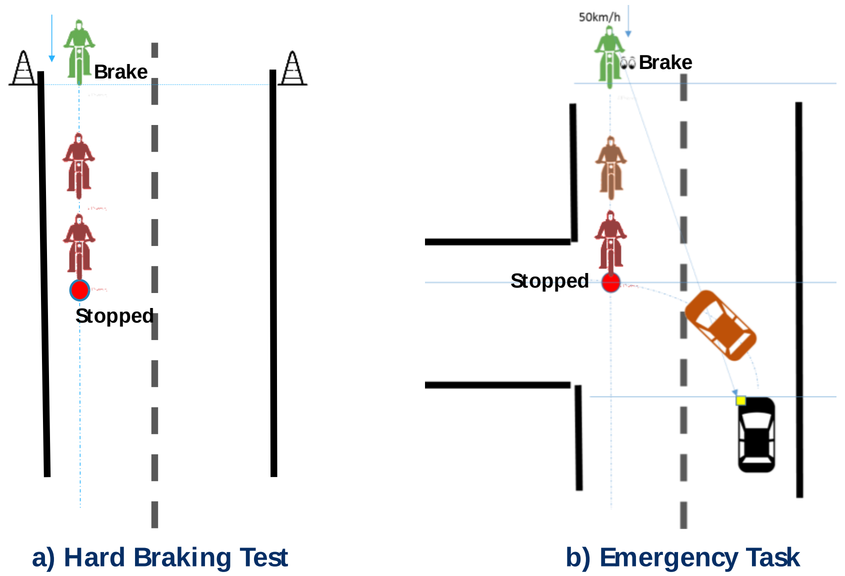


Figure 4-35. Diagram of Hard braking test (a) and Emergency task defined (b)

Additionally to the variables effective and maximum deceleration used to compare the two different tests, the initial jerk $jerk_{ini}$ (deceleration gradient), see Figure 4-36, defined as the average jerk between the start of the braking period (T_{j1}) and the instant where the deceleration curve reaches 4.5m/s^2 (T_{j2}) was selected as a kinematic parameter of the braking pattern (equation 8). The value of 4.5m/s^2 was selected to assure a maximum deceleration that all the participants could achieve during the first phase of braking, making possible the comparison of all the trials of the riders from the lowest to the highest braking competency.

$$jerk_{ini} = \frac{dec_{long}[T_{j2}] - dec_{long}[T_{j1}]}{T_{j2} - T_{j1}} = \frac{4.5\ m/s^2}{\Delta T} \tag{8}$$

To test the hypothesis that braking in response to an unpredicted stimulus versus pre-planned braking differs in performance outcomes, a linear mixed-effects model was done including

Type of trial as fixed factor and crossed random effects for *Trial order* and *Rider* with random slope and intercepts (accounting for baseline differences between riders). The best fit model for each variable was defined by the number of parameters and the -2 Log likelihood values of the model.

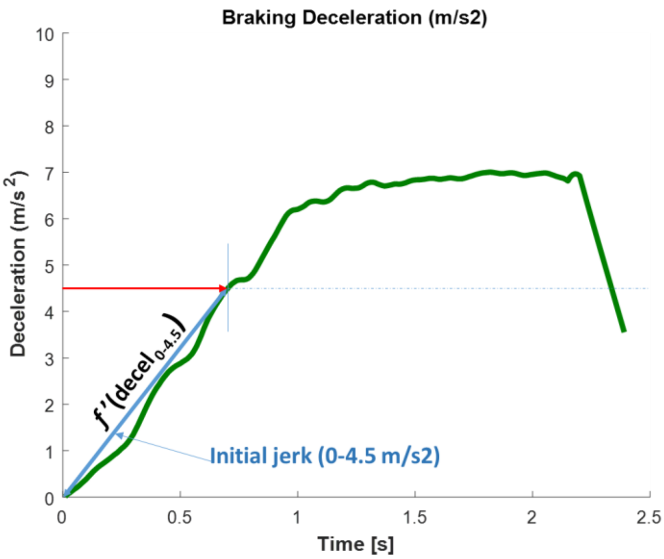


Figure 4-36. Representation of parameter Initial Jerk (*jerk$_{ini}$*)

5. Emergency braking task – Results

This chapter presents the results of the analysis of perception skills based on the response time and the analysis of control skills with the braking manoeuver.

The response time is measured synchronizing video analysis with signals from the pressure sensors on brakes.

The braking performance is measured using the time series deceleration of the stopping manoeuver with two different approaches that classify group of riders based on their level skills. One analysis uses the two most representative parameters of the deceleration (effective deceleration and maximum deceleration). In a next step, to characterize the interaction of the rider with the vehicle (section 5.3), different parameters from the dynamic signals collected have been defined and computed. The purpose was to understand the main differences in the actions of the most skilled riders with respect to the less skilled riders to characterize the brake interaction rider-vehicle. A regression model with the collected data and the key parameters defined has been made to predict the braking distance and deceleration rate. The model defined will be able to predict the reduction of the braking distance as function of the parameters of interaction rider-vehicle. In addition, the model developed may support the definition of specific targets during training process.

Another analysis uses the whole time series deceleration with functional data analysis to classify the different patterns of braking.

Finally, the chapter presents a complementary study braking behaviour of the participants comparing a conventional hard braking test with the emergency braking task designed in this thesis. The aim is to know if the test designed provides some differences compared to the standard hard braking tests that make the response of the riders closer to a real world scenario.

5.1. Perception Skills: Response Time

In this section 246 tests are initially analyzed. The 123 tests with instructions to go straight without braking on the intersection (IS and GS) where analysed to measure the reliability of the rider based on the *unwanted braking* actions without the onset of the car turning.

The 123 tests where the car in opposite direction was turning (NT and IT scenarios) were analysed to determine the response time of the braking manoeuver. The response time has been analysed following the methods explained in the previous chapter.

5.1.1. Selection of valid tests

The first step of the analysis evaluated if the participants were following the instructions of the procedure, i.e., to start braking only AFTER perceiving the hazard of a car turning in front of the motorcycle. The aim was to check whether the response time of the riders were due to a perception of a real hazard (i.e. car was actually turning in front) or just a preventive action when getting close to the intersection that the rider was doing systematically. The measure to assess the reliability of the participants' performance was the percentage of *unwanted braking* (%), i.e. cases with rider braking when the car was not turning (Figure 5-1). The scores for each participant were averaged by dividing the number of wrong prediction with *unwanted braking* trials by the total trials with scenarios IS and GS. The sample analysed was a total of 123 trials. Due to missing data, some riders had less than 10 trials available for the analysis. Figure 5-1 shows that the IS scenario incited to *unwanted braking* at least once for most riders (10 of 13 participants). Low percentage of *unwanted braking* was considered acceptable as a natural part of the procedure and the adaptation of the participants in an environment where they had to take decisions in a very short time interval. However, riders S02, S09, S08 and S07 started to brake in more than 75% of the IS cases. These four riders were potentially not reliable with the tests where the turn indicator was activated. Besides, S07 and in a more evident way S09, failed also predicting the hazard when the car was going straight (GS).

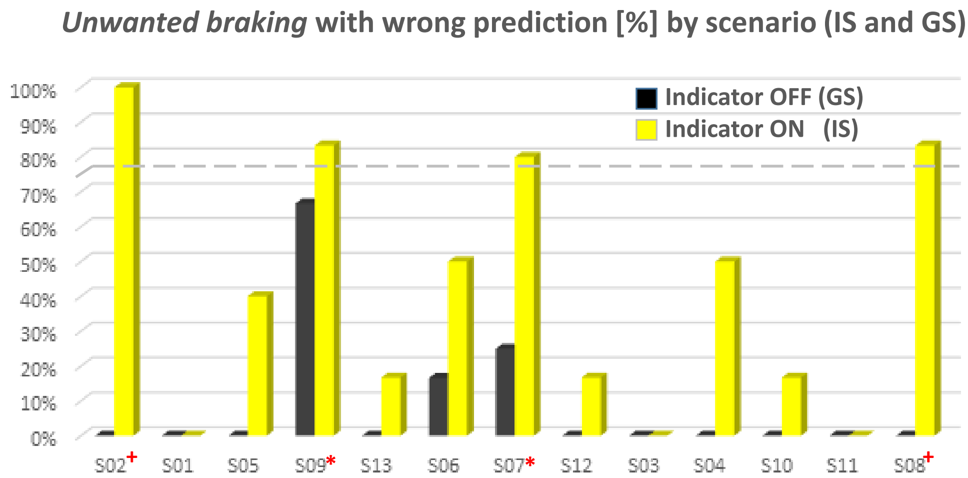


Figure 5-1. Percentage of miserception of the hazard per subject (Total N=123). *Subjects with high values of wrong prediction. +Subjects with high values of wrong prediction in IS scenario.

5.1.2. **Braking Response time and identification of levels of competencies**

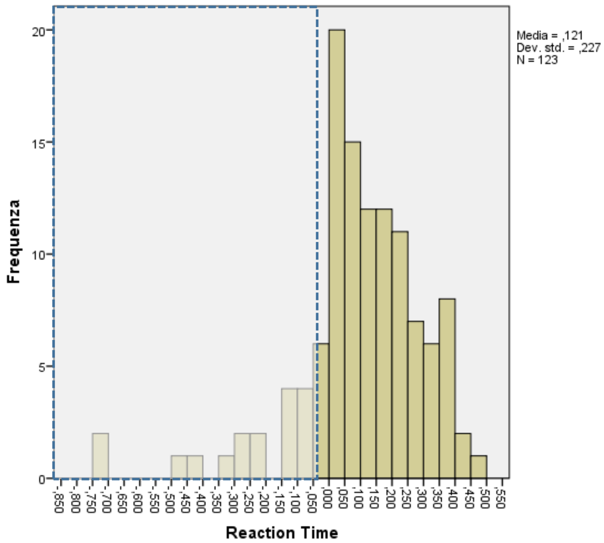
Descriptive Results

The response time (RT) results are presented per subject and per scenario (IT and NT). As can be seen in Figure 5-2, there are a few results where the RT is negative, i.e., the rider started to brake before the onset of the hazard measured by video analysis. There are two possible explanations of this. First, the participants started to brake as a preventive action even when they were not sure the car was actually turning. This is linked with the previous analysis that detected the riders that were more prone to brake preventively without the car turning and with response time (RT) values negatives. The second explanation is that riders were able to learn during the experiment, so in a three-dimensional dynamic scenario some riders could predict that the car would turn based on stimula that are not perceived in a 2-D frame by frame analysis. As some participants, including S01, S10, S11, S12, and S13, were considered very reliable, because they did not predicted wrongly the car turning in the IS and GS scenarios (section 5.1.1), the low values of RT for them were interpreted as consequence of this second explanation.

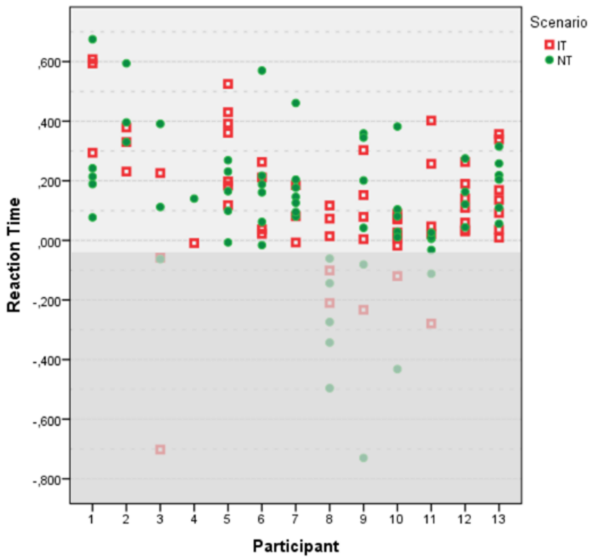
Considering this, and after assessing the distribution of the RT measures (Figure 5-2ab), it was determined that the gap around -0.035 seconds found in the scattered plot of Figure 5-2b represented the minimum RT reliable. This a threshold that does not exclude most of the trials of the riders that showed a reliable response in IS and GS scenarios. Consequently, RT of 17 trials below -0.035 seconds were removed from the analysis (grey area in Figure 5-2ab). The final sample of measures of RT corresponded to 106 braking trials.

As predicted in the previous section 5.1.1 the participants with more trials considered not valid were S08 (7 trials) and S09 (3 trials). In addition, participants S03 and S04 have a reduced sample of valid tests with three and two values of response time respectively due to problems with the light conditions of the video registered and fails in the signals (common in experimental studies). Accordingly, the sample of 106 braking trials was not completely balanced by subject.

The remaining response time values of subject S08, because of the high number of tests rejected and the high percentage of cases of misperception with the IS scenario, are susceptible to be non-reliable.



a)



b)

Figure 5-2. Distribution of the response time measures. a) Histogram; b) Scattered plot

The results of this study differ from the existing literature on braking response time on PTWs (Davoodi et al., 2011, 2012; Ecker, Wassermann, Ruspekhofer, et al., 2001; Thom, Arao, & Hancock, 1985) which used alerted riders with a static stimulus with RT averages in the range of 0.40-0.68 seconds. From this studies the lowest RT was 0.19 seconds, measured by Davoodi et al. (2012).

Exploration of RT of elite-standard sprinters in athletics set the minimum response time for a simple auditory stimulus to 0.115s (Brosnan, Hayes, & Harrison, 2017). Considering this, it was assumed that some riders were able to predict that the car would turn even before the car started to turn left in front of the PTW according to the 2D video analysis frame by frame.

To compensate this anticipation detected it was decided to add an offset of 0.150s to all the RT values of the study, so the lowest accepted value of the sample (-0.032s) becomes 0.118s, a RT comparable with those 0.115s considered the minimum response time for sprinters. Although this is a rough estimation it may works to put the values of the RT measures in a more realistic reference. The average response time per subject and scenario adding the 0.150s offset are shown in Table 5-1 and Figure 5-3.

Table 5-1. Response time (s) per subject with offset added of +0.150 seconds

Subject ID	Mean	Std dev.	Mean IT	Mean NT	N (IT)	N (NT)	N
2	0.53	0.12	0.46	0.59	3	3	6
1	0.51	0.23	0.65	0.43	3	5	8
5	0.40	0.15	0.47	0.30	7	5	12
3†	0.39	0.14	0.38	0.40	1	2	3
9	0.34	0.14	0.28	0.39	4	4	8
13	0.33	0.12	0.31	0.34	7	6	13
6	0.32	0.17	0.28	0.35	4	6	10
7	0.30	0.12	0.24*	0.33	3*	7	10
12	0.28	0.09	0.27	0.30	7	4	11
11	0.24	0.15	0.33	0.15	4	4	8
10	0.22	0.10	0.19	0.27	7	5	12
8*	0.22	0.05	0.22	-	3*	0	3
4†	0.22	0.11	0.14	0.29	1	1	2
Tot.	0.33	0.16	0.32	0.33	54	52	106

*Subject with measures not reliable; † Subject with sample size N≤3

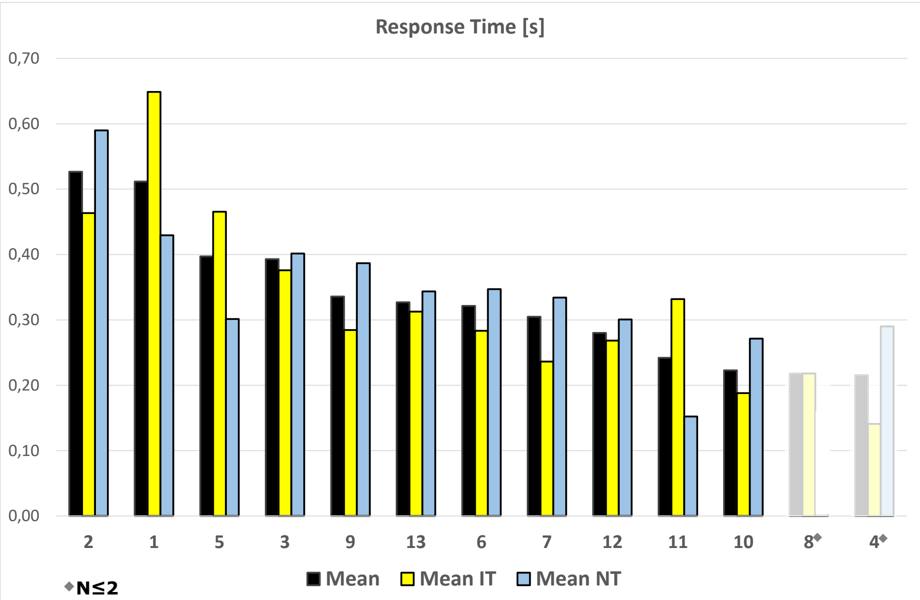


Figure 5-3. Average Reaction Time per subject and Scenario (offset of +0.150s applied)

Statistical Analysis

The one way ANOVA analysis indicates that the subject is a significant factor (p< .001) that affects the response time. The analysis excluded subjects S08, considered not reliable and S04 because there were only two measures. The post-hoc Tukey analysis (Table 5-2) shows the three different groups of riders with no significant differences among them. Thus, the test proposed is a task that can find differences between subjects based on their response time. The group of riders with Perception Skill 'B - Intermediate' (see Table 5.2) with a response time range [304-397ms] have no significant differences with the rest of the riders. However the subjects level 'C- Advanced' with best results S10 and S11 are clearly separated from S01 and S02 (level 'A-'), the two riders with higher response time. The response time of S12 is also statistically lower than S02 and is lower than S01 with p=.060. Based on these results, it is possible to set three different levels with range for the response time: Low skilled (A) [450-600ms]; Intermedium Skilled (B) [300-450ms]; High skilled (C) [200-300ms]. As commented above, because of the variability of the response of the subjects, the participants of this study assigned as level B-Intermedium, actually do not present significant differences with participant from level A-Beginner or C-Advanced.

Table 5-2. Response time (s) values including the 150ms offset. Post-Hoc Tukey Analysis with the skill level assignment.

Perception Skill Assigned	Subject	N	Group 1	Group 2	Group 3	Response Time	Distance (v=50km/h)
C –Advanced	10	12	0.222				
	11	8	0.242			200-300ms	2.8-4.2m
C –Advanced	12	11	0.280	0.280			
	7	10	0.304	0.304	0.304		
	6	10	0.321	0.321	0.321		
B– Intermed.	13	13	0.326	0.326	0.326	300-450ms	4.2-6.25m
	9	8	0.335	0.335	0.335		
	3	3	0.393	0.393	0.393		
	5	12	0.397	0.397	0.397		
A– Beginner	1	8		0.511	0.511		
A– Beginner	2	6			0.526	450-600ms	6.25-8.3m
	Sign.*		.355	.060	.085		

*alpha = .05

It is important to note that, as has been commented, the light condition was a not controlled factor during the experiments (sunny or cloudy, midday or afternoon). It was noted during the experiments that S01, classified as perception skill level 'A', had the sun in front of the eyes during part of the experiment, so this factor probably affected his performance.

Effect of the Turning Indicator

The repeated measures ANOVA with the average of the response time per scenario per subject indicates that the presence of the turning indicator when the car was turning, did not affect the response time of the participants (p=.785). Moreover, interaction between scenario and level skill was not significant neither (p=.817).

Learning effect

To measure the learning effect of the riders during the experiment, it was done a repeated measures ANOVA with response time (RT) as dependent variable and two independent variables: Round with two levels, Round 1 and Round 3 (each round had 8 trials); and Skill Level with two levels, 'B'(Intermediate) and 'C'(Advanced). The median of the measures of each subject of level skills in each round was used for the analysis.

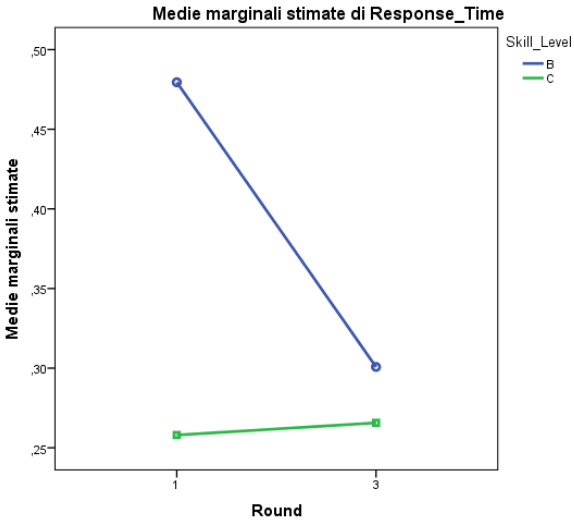


Figure 5-4. Marginal means of Response time (s) for group of riders Skill level 'B'(Intermediate) and 'C'(Advanced).

The results indicate a significance of p=.065 of the factor 'Round' and p=.05 for the interaction 'Round' and 'Skill Level'. As can be observed in the graph of the marginal means, it seems that although the riders with shortest response time (level 'C'-Advanced) are consistent during the whole test, the riders with intermediate skill level (level 'B'-Intermediate) improve reducing the response time. The two riders from level 'A'-Beginner had different behaviour between them and were not included in the analysis.

Consistency of the measures: Intra-class correlation

The video analysis was carried out by a master student previously trained and supervised by the author of this thesis. A subset of 12 braking trials (three trials per 4 different riders) with different light conditions was analysed twice by the same evaluator within a gap of a 3 weeks to measure the consistency of the measures.

The average variation between the two video analysis of the same subset is 0.078 seconds (standard deviation ±0.046). The average coefficient variation per subject between the two measures was 0.076 seconds (standard deviation ±0.040). This variation per test and subject is the time equivalent to 2.3 frames step (fs) of the software used to detect the onset (fs=0.033s).

Table 5-3. Difference between first and second video-identification of the onset of car turning (s)

	S04	S07	S09	S11
Trial A	0.077	-0.054	0.002	0.101
Trial B	0.097	-0.127	-0.126	0.062
Trial C	0.037	0.014	-0.096	0.146
Average*	0.070	0.065	0.075	0.103
Total Average Variation*:	0.078		**SD:** ±0.046	

*average of absolute values

The differences between the two video analysis of the three trials for 4 riders are showed in Figure 5-5.

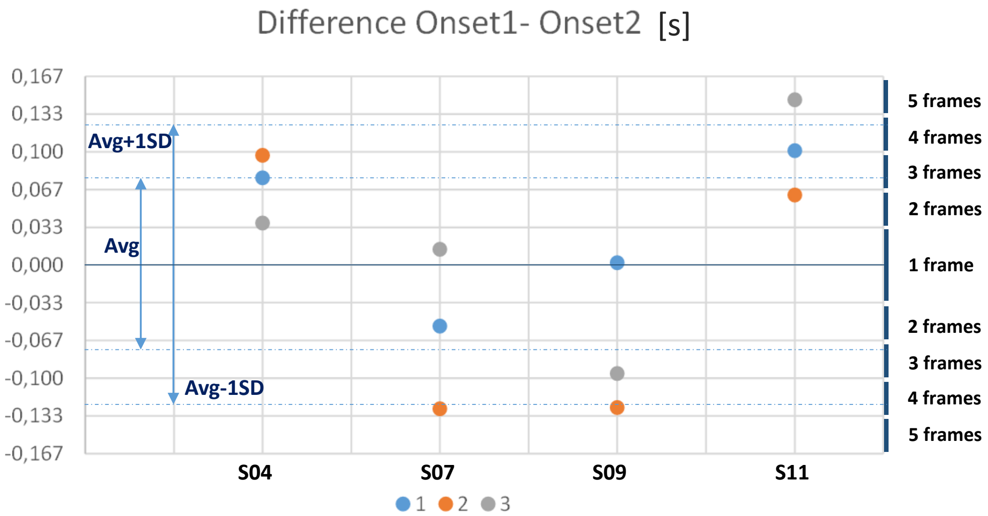


Figure 5-5. Difference between the two identification of the onset to measure consistency

Intra class correlation (ICC) of the two different measures was calculated to assess the consistency of the video analysis rater identifying the onset of the car turning. The ICC indicated good consistency of the measures (Cronbach's alpha = 0.913).

Conclusions

The response time is a parameter related to the perception skills of the riders and it has significant differences among different riders. Intermediate riders have shown a learning effect during the experiments presenting the best response at the end of the experiment. This suggests that the experiment works as a method to improve perception skills. Lowest skill riders may need more test sessions to improve their performance. In the case that the rider has also low control skills, the progress in a task with high order of hierarchical complexity level like perception skills will come after the improvement of the lowest behavioural level (operational tasks). The riders with shortest response time (level C - Advanced) have a great capacity to predict the cue of the car turning since the beginning of the tests and they keep the high performance during all the trials. How the improvement of the perception skills during the test is transferred to real world and how it is retained by riders may be of interest for future studies.

The task designed emulates a realistic scenario, where the rider must scan and detect the cue in a dynamic 3D environment. The realism of the task designed helps to develop visuo-motor skills, but makes difficult to set the real onset perceived by the riders, since unlike previous studies, there is not a specific located and motionless target to check (as a light or screen panel). This makes the values found less comparable with previous studies in terms of quantifying the reaction time of the riders. However, the study reveals new insights about the learning capacity to predict the hazard in dynamics. Rosalie & Müller (2012) defined the ability to anticipate the eventual position of an object in motion as a key component of perceptual-motor skill. The results suggest that riders during the experiment, in a 3D motion environment, are able to learn to use advanced cues to predict the car turned even before the car had started the turning left manoeuver.

5.2. Control Skills: Braking Performance

5.2.1. Deceleration: Effective and Maximum - Braking indicators[5]

Descriptive Analysis

The two parameters used to assess the performance in this first phase were effective and maximum deceleration (Figure 5-6).

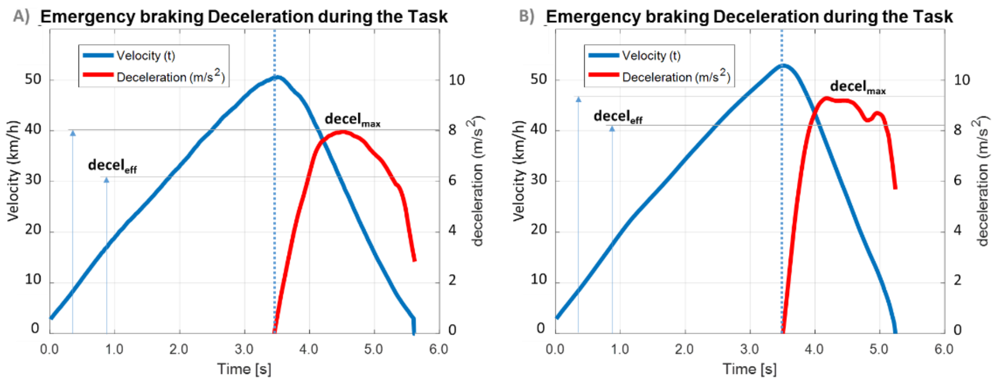


Figure 5-6. Example of time series of deceleration during two emergency braking trials

This section presents the results of the analysis of PTW dynamics recorded during 157 emergency braking trials in which the car actually began a turn in front of the rider (both scenarios IT and NT), performed by 13 riders of varying skill levels. The sample included the cases excluded in the analysis of the response time, since during the experiment it was considered that the participants performed the hard braking manoeuver following the instructions of the task independently of their perception performance. Only the cases where the riders did not completed a full stop were removed. The sample is well balanced by riders, with most of the riders with 11/13 braking trials, and only S02 and S09 have 8 trials because they went straight instead of braking in a few braking trials.

[5] Results presented in (Pedro Huertas-Leyva et al., 2017)

The mean and standard deviation (SD) of effective and maximum deceleration per subject during the emergency task is shown in Table 5-4. The subjects are sorted by effective deceleration (from 3.83 to 8.05 m/s^2). The two women from the sample (S02 novice rider and S08 rider with experience) presented the lower deceleration rates.

Table 5-4. Results of effective and maximum deceleration

	Dec. Effective		**Dec. Maximum**		
Subject ID	Mean	SD	Mean	SD	N
2	3.83	0.83	5.03	0.85	7
8	4.77	0.79	6.11	0.29	13
9	5.15	0.65	6.48	0.45	10
6	5.54	0.63	6.80	0.33	11
12	5.68	0.73	7.62	0.61	13
10	6.55	0.62	8.98	0.40	15
1	6.65	0.23	9.13	0.51	13
11	6.65	0.65	8.31	0.53	12
3	6.70	0.92	8.61	0.41	13
13	7.11	0.61	9.08	0.48	13
7	7.14	0.75	8.95	0.20	12
5	8.00	0.35	9.94	0.35	12
4	8.05	0.61	9.70	0.59	13
Total	6.40	1.28	8.18	1.49	157

Skill differences in braking performance (deceleration)

The results of the ANOVA on effective and peak deceleration revealed that there are significant differences in performance across riders ($p < .001$). The Tukey post-hoc tests of effective and peak deceleration (*alpha* set at 0.05) identified 4 groups of riders differing significantly in effective and maximum deceleration that were composed by the same subjects in both variables (Table 5-5 and Table 5-6). This is an interesting finding, since besides the effective deceleration (with a direct relationship with the braking distance), the maximum deceleration achieved is also revealed as a parameter that characterizes the skill level of the riders. The groups were defined as 'A' novice (1 subject), 'B' intermediate (4 subjects), 'C' advanced (6 subjects) and 'D' expert (2 subjects).

Table 5-5. Deceleration (effective) - Post-Hoc Tukey with alpha=0.05

Skill Assigned	**Subject**	**N**	**1**	**2**	**3**	**4**	**5**
-A- Novice	2	7	3.83				
-B-	8	13		4.77			
Intermediate	9	10		5.15	5.15		
	6	11		5.54	5.54		
	12	13			5.68		
-C-	10	15				6.55	
	11	12				6.65	
Advanced	1	13				6.65	
	3	13				6.70	
	13	13				7.11	
	7	12				7.14	
-D- Expert	5	12					8.00
	4	13					8.05

Table 5-6. Deceleration (max) - Post-Hoc Tukey with alpha=0.05

Skill Assigned	Subject	N	1	2	3	4	5	6	7
-A- Novice	2	7	5.03						
-B-	8	13		6.11					
Intermediate	9	10		6.48	6.48				
	6	11			6.80				
	12*	13				7.62			
-C-	11	12					8.31		
	3	13					8.61	8.61	
Advanced	7	12						8.95	
	10	15						8.98	
	13	13						9.08	
	1	12						9.13	
-D- Expert	4	13							9.70
	5	12							9.94

*S12 has higher level than the rest of the riders from group 'B' and lower than the riders from group 'C'

Table 5-7 lists the means, CI_{95} and standard deviations (SD) for effective and maximum deceleration for each group found. Group 'A' novice contains only the 7 trials of the novice rider as commented previously. It is important to note that standard deviation of the groups in effective and maximum deceleration is inversely proportional to skill with both decreasing as skill increases.

Table 5-7. Mean, CI_{95} and SD by Skill Level Group for Effective and Maximum Deceleration (m/s^2)

	Decel. Effective				Decel. Max				Riders	Trials
Skill Level	Mean	SD	CI_{95}[low-	up]	Mean	SD	CI_{95}[low-	up]	N	N
A - Novice	3.83	0.83	3,06	4,59	5.03	0.85	4,24	5,81	7	1
B - Interm	5.28	0.78	5,06	5,51	6.73	0.69	6,52	6,93	47	4
C - Advanc	6.79	0.68	6,64	6,95	8.82	0.63	8,68	8,96	78	6
D - Expert	8.03	0.49	7,82	8,23	9.82	0.50	8,77	10,03	25	2
Total	6.40	1.28			8.18	1.45			13	157

Figure 5-6 and Figure 5-7 show the distributions for the effective and maximum deceleration values for the 157 emergency braking test (both NT and IT) labeled by skill group of riders (7-13 data points per rider). The lines separating each groups correspond to deceleration thresholds defined by the "mean ±1SD" of the Table 5-7. The distribution of the braking performance shows four groups clearly divided in both charts.

The expert group is more clearly separated from group "C – Advanced" in the effective deceleration. For the group "D - Expert", 7.5 m/s^2 represents the lower limit for effective deceleration in the emergency braking task. Interestingly, the distribution of the maximum deceleration shows a clear 'gap' that separates level "C – Advanced" from level "B – Intermediate" at 8.0 m/s^2. This value may be related with a threshold where the control of the PTW requires a higher level, so less skilled riders pertain below this deceleration.

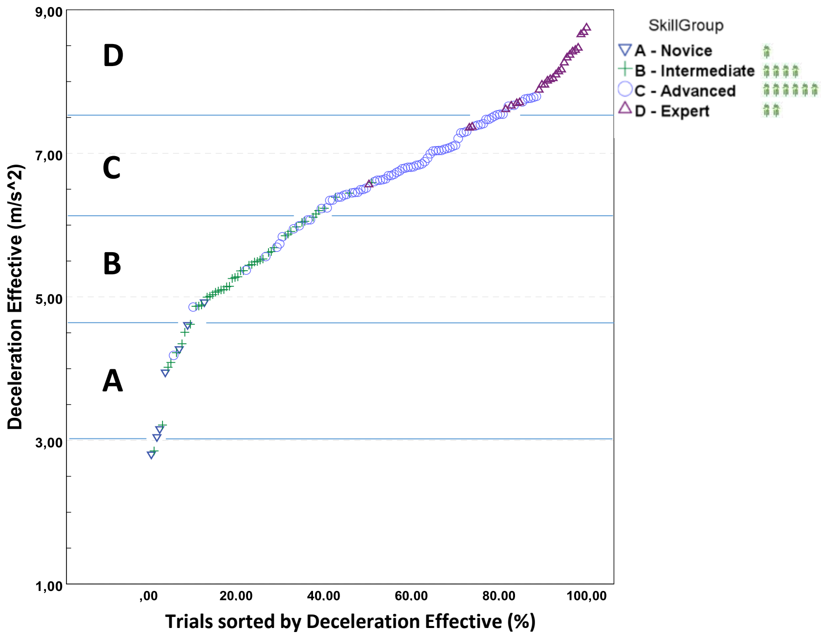


Figure 5-7. Distributions of effective deceleration. For axis X, '0' represents the lower deceleration and '100' the highest effective deceleration. N= 157.

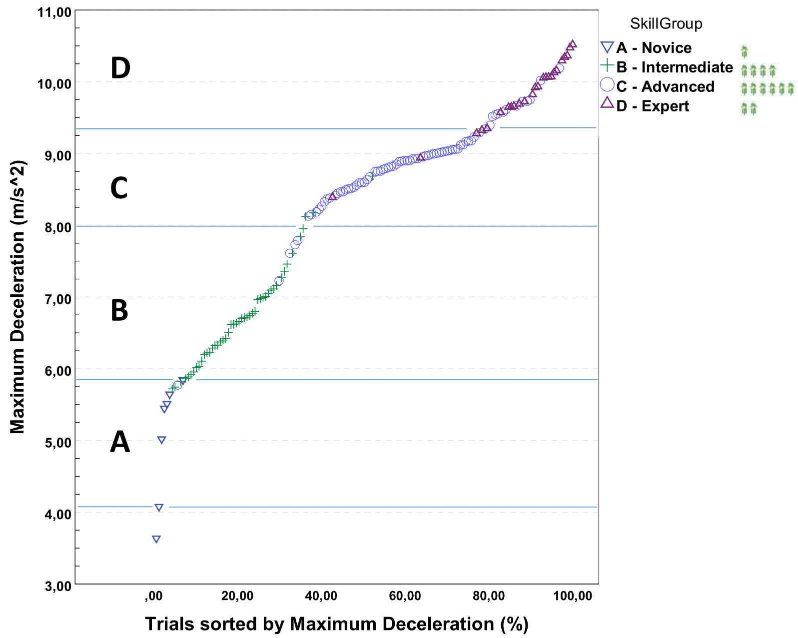


Figure 5-8. Distributions of maximum deceleration. For axis X, '0' represents the lower deceleration and '100' the highest maximum deceleration. N= 157.

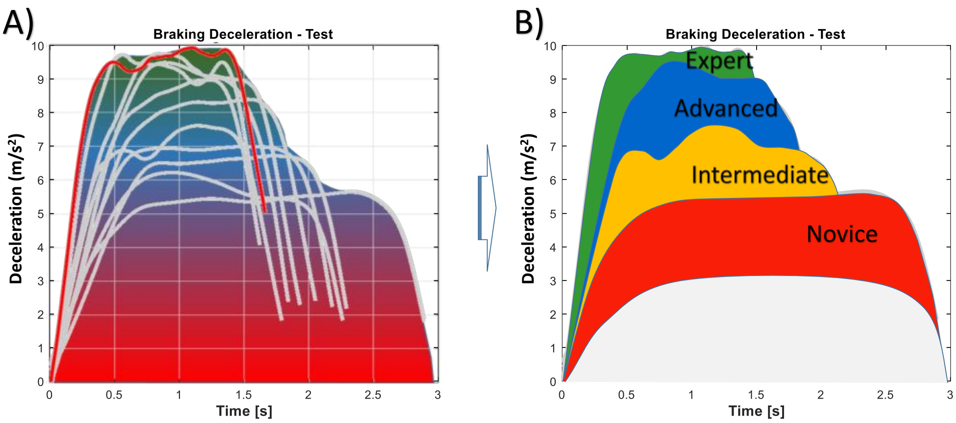


Figure 5-9. A) Time series deceleration of participants; B) Classification of skill levels

Figure 5-9 shows the time series deceleration per each participant. For this figure, each participant is represented by the trial corresponding to the median of the effective deceleration. The figure shows the wide variability of the performance of the participants, and the classification of the different groups of riders based on their effective and maximum deceleration.

Effect of turn indicator on braking performance

Results of the repeated measures ANOVA to test for effect of NT versus IT trials on effective deceleration by subject, showed that activation of the turn indicator during the emergency braking trials had a significant effect (p = .013). Most riders exhibited a reduction of the performance (lower effective decelerations) when the turn indicator of the opposite car was 'on' before turning (IT scenario). This did not appear to be the case for the two expert riders in group D. Deceleration values by subject ID are listed in Table 5-8.

Table 5-8. Values of mean of effective deceleration (m/s^2) per subject and level skill group.

		IT	NT
Level	**ID**	**Mean (SD)**	**Mean (SD)**
A	S02	3.24 (0.49)	4.60 (0.33)
B	S08	4.32 (1.00)	5.17 (0.17)
	S09	5.12 (0.83)	5.18 (0.52)
	S06	5.15 (0.66)	5.88 (0.45)
	S12	5.51 (0.95)	5.81 (0.52)
C	S11	6.60 (0.20)	6.71 (0.26)
	S10	6.40 (0.74)	6.72 (0.42)
	S01	6.59 (0.47)	6.72 (0.86)
	S03	6.39 (1.29)	6.96 (0.38)
	S07	7.54 (0.16)	6.74 (0.90)
	S13	7.05 (0.45)	7.16 (0.76)
D	S05	8.04 (0.23)	7.96 (0.46)
	S04	7.92 (0.75)	8.16 (0.49)

Indicators may act as a distracting component in lower skilled riders that perform the braking manoeuver under higher cognitive load. Another hypothesis could be that the use of the turn indicator is perceived by the riders as a “pre-calculated” manoeuver of the car driver (not a last second one), and consequently the participant feels that it is not an emergency scenario and the car driver will stop.

This result has to be carefully considered since there is a large within-subject variability for most riders (see Figure 5-10). This variability could be due to a learning effect across trials.

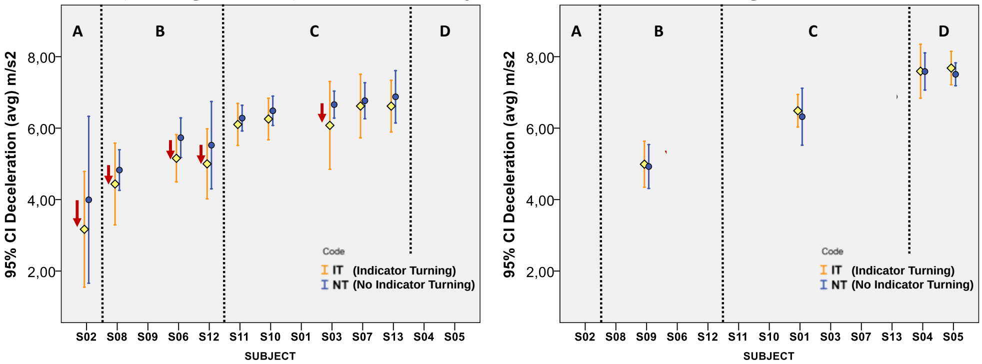


Figure 5-10. 95% Confidence Interval for effective deceleration braking by Scenario and Group of Riders

Conclusions

Acceleration profiles obtained with a frequency sampling of 100Hz provide an objective measure of performance. The test designed for this study and the sample representing a wide range of braking performance have made possible to set a criterion to define 4 different competency profiles based on the maximum deceleration achieved and the effective deceleration. The 4 braking skill profiles help to label the real competencies of a rider beyond a simple value of deceleration. Some considerations about the effect of ergonomics have to be taken into account.

Looking at the profile of the participants, the results also showed that the lower braking deceleration are achieved by the two women of the sample (subjects 2 novice and subject 8 with medium experience). Those results, assumed as consequence of braking skills, may support the hypothesis of the effect of ergonomics (e.g. height and weight of the PTW, brake lever far from the rider’s hand) and of a muscular issue to support strong deceleration "in the arm" that causes less performance in women. It is also important to note that during the tests and the previous familiar phase, the researchers perceived that the experts needed less time to get familiar/confident to the scooter PTW of the experiment. During this process the riders needed to “adjust” their internal automatized control models to the dynamics of the new vehicle (Summala, 1988). In some cases, this adjustment of the internal control model may continue during the whole test for less skilled riders. Likewise, the riders that did not get use to ride moto-scooter could need longer time to adapt their skills. Performing emergency braking tasks with a vehicle non familiar to the participants may be a factor that enhances the differences between high and low skill riders.

The high variability of rider levels, suggests that these 4 groups may apply not only to the sample of the study. The threshold values found that separate the 4 groups may be used as a general indication for the emergency braking tests assessments. The next step is to understand what the high skilled riders do different from low skilled riders to perform the hard braking.

The mean of effective deceleration for experts (8.03 m/s2) and for advanced (6.79 m/s2) riders found in this study are in agreement to the values found by Vavryn & Winkelbauer (2004). Although the vehicles and test procedure differed (e.g. perception-action coupling approach), experienced riders from Vavryn and Winkelbauer's study achieved similar performance (7.8 m/s2 braking on a PTW with ABS and 6.6 m/s2 riding their own vehicles). The maximum deceleration within CI95 upper limit we found for experts (10.03 m/s2) is also similar to the 10-11 m/s2 found by Ecker, Wassermann, Hauer, et al. (2001)measuring with an instrumented motorcycle. As it has be pointed in the section 3.1.3, data from in-depth accident cases estimate that in case of the need of a critical avoidance response the brake effective deceleration needed to avoid collisions for an average time to react of 2 seconds is around 6.94m/s2. This means that only expert riders could avoid part of the accidents if they were able to perform in the same way in real emergency scenarios (and with dry asphalt). This remarks the importance of the braking skills, but it mainly highlights the importance of defensive riding and perceiving the hazard in advance, since even experts would not avoid collision in the cases where the time to react is shorter than the 2 seconds running at 50km/h or where the speed is higher than 50km/h with 2 seconds to react.

The results also showed that higher skill was associated with less variation in effective and peak deceleration across trials. Increasing consistency of motor skill performance is commonly associated with increasing skill (Magill and Anderson, 2016). The present study improves on the accuracy of certain measurements obtained in previous studies. Davoodi & Hamid, (2013) and Vavryn & Winkelbauer (2004), determined deceleration rates indirectly from measures of distance, instead, we used instantaneous deceleration sampled at 0.01s intervals and then averaged across trials and participants. The nesting of samples in this manner gives a detailed picture of the time evolution of deceleration within each emergency event and across situations. This study has also found the possible limitations of de identification of the onset of braking by visually determining the timing of brake light illumination. While the brake light activates the moment that the brake lever is pressed, it has been found during this study that there is a time delay between activation of the brake light switch and the contact occurring between the brake pads and brake disc which makes the onset of actual braking. Actually, it is possible for the brake light to be activated without enough braking pressure to be generated to effectively produce deceleration, giving inaccurate measures of the onset time of intended braking.

Anderson & Baxter (2010) computed the constant higher deceleration values using the measure of the speed with a laser, but the goal was to study the braking systems and they used one expert rider as tester. Our study differs markedly from previous studies on braking due to the additional cognitive workload demanded of the riders, since they were required to perceive and predict the movements of an opponent vehicle, and not simply respond to a static light signal. Indeed, we found that use of the indicator before turning (a distracting or misleading stimulus) had a negative effect on braking performance, particularly for the least skilled riders. Future research about learning effect of the riders may study if the effect of a distracting component is significant only during the first stage of the training and can be overcome afterwards.

The characterization of different skill profiles based on deceleration parameters improves understanding of rider ability and limitations in the performance of emergency manoeuvres. In terms of design of safety systems like autonomous braking, the results suggest that there is not an optimal deceleration pattern to be applied to all the riders, but different rider profiles will have different optimum deceleration curves. Same deceleration pattern in an autonomous braking system that may bring to loss control in less skilled riders, at the same time, may be undersized for highest skilled riders. The emergency test designed may help to classify the rider skills in order to future customization of safety systems.

5.2.2. Deceleration: Functional Data Analysis of Deceleration

First, the discrete time series of deceleration were scaled and converted to functional data using B-Splines as basis functions (Figure 5-11). The functional average of all the deceleration functions $F_{avg}(t)$ was also computed.

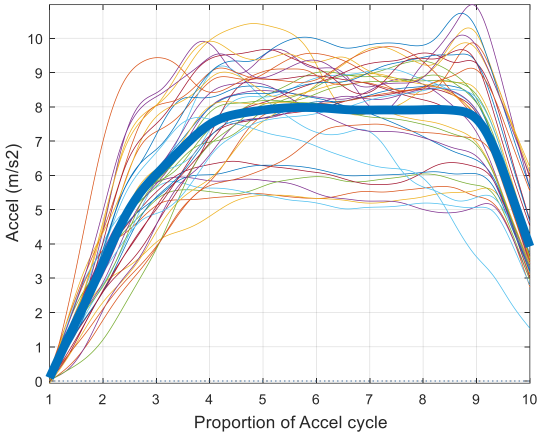


Figure 5-11. Time series converted to functional data. $F_{avg}(t)$ *in blue line.*

Next, FPCA was computed. FPCA defines a base of independent functions that can be combined to explain all the observed variability. The FPCA with 3 harmonics using Varimax rotation determines three independent functions that summarize the 96% of the variability of the deceleration time series of the tests (Figure 5-12). The first harmonic (PCA function I) is related to the maximum deceleration and represents a 43%, the second harmonic (PCA function II) has more relationship with the time to achieve the maximum deceleration (22%) and the third harmonic (PCA function III) seems more related to the second peak or the time that the high deceleration is kept (31%).

Thus, the time series deceleration of every braking trials $decel_{iFPCA}(t)$ may be defined as the combination of the three harmonics computed, where each harmonic has specific score that characterize the test, following the equivalence,

$$decel_{iFPCA}(t) = F_{avg}(t) + score_{i1} * PCA_1(t) + score_{i2} * PCA_2(t) + score_{i3} * PCA_3(t)$$

where F_{avg}(t) is the functional average of *decel(t)* for all trials, $PCA_j(t)$ are the *j-th* harmonic of functional principal components, and $score_{ij}$ are the scores of the *i-th* trial for component $PCA_j(t)$.

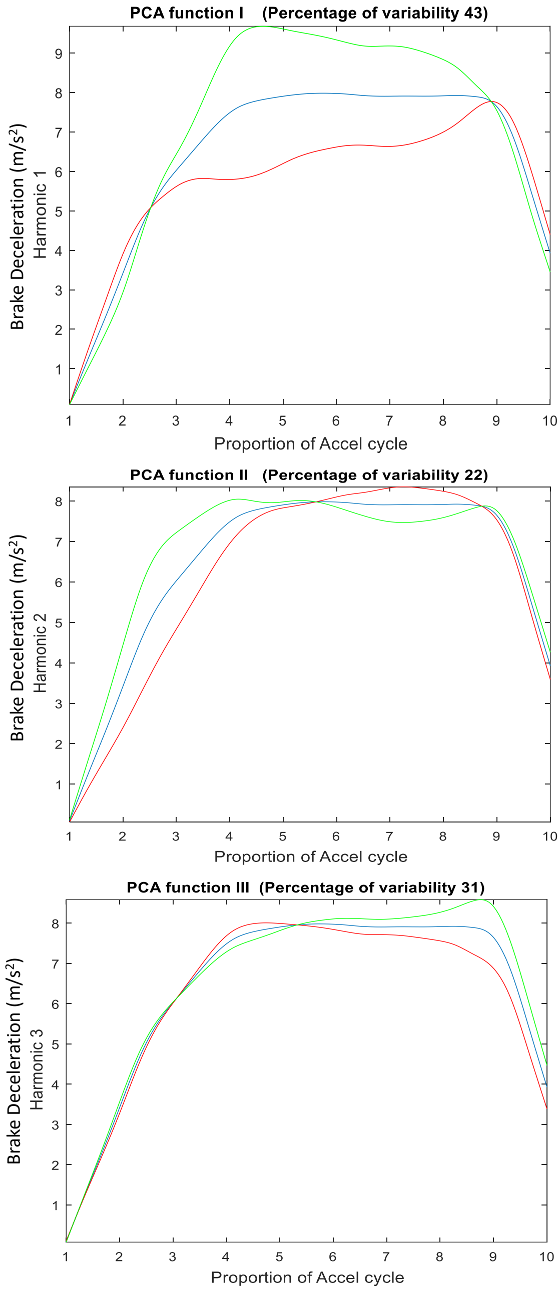


Figure 5-12. Representation of the three harmonics of the FPCA. Average of all the tests F_{avg} (blue); F_{avg} plus PCA_j Harmonic (green); and F_{avg} minus PCA_j Harmonic (red).

Figure 5-13 presents an example of two different time series from two braking trials of two different riders where smoothed green line is the $decel_{iFPCA}(t)$ from the FPCA combination and the black line is the original time series *decel(t).*

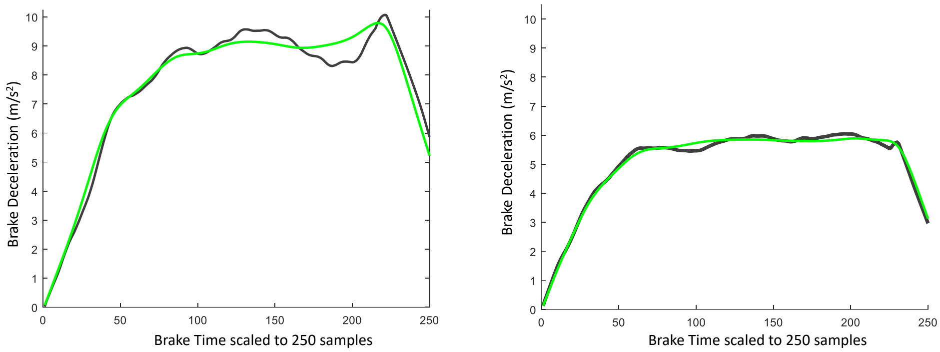


Figure 5-13. Example for two different riders: *$decel_{iFPCA}$(t)* (green) and *decel(t) smoothed* (black)

A 3D representation of the three scores of a subsample of tests of 8 participants with different levels shows the different clusters based on the times series data of the deceleration (Figure 5-14).

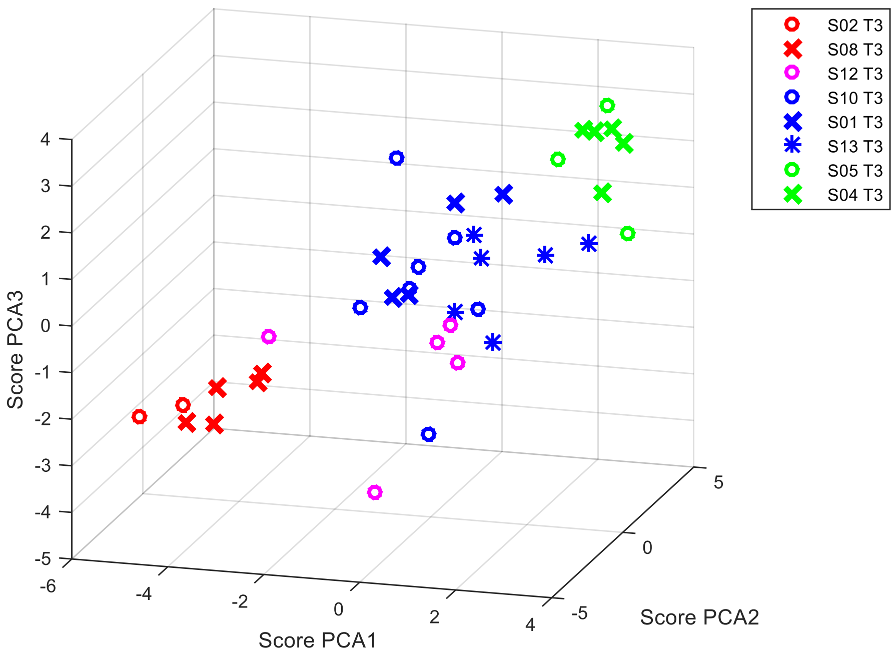


Figure 5-14. 3D Representation of the Scores for the different tests by rider. Colors represent the different skills levels (red: low; magenta: intermediate; blue: advanced; green: expert)

Figure 5-15, Figure 5-16 and Figure 5-17 shows the distribution of the scores of the three PCA functions in 2D representation. The clusters are similar to the skill groups defined in section 5.2.1, except that the 4 groups are reduced to 3 groups with the S08 that is 'downgraded' to novice and S12 should be included in the group of advanced riders. Two test from the advanced rider S13 are also close to the expert performance.

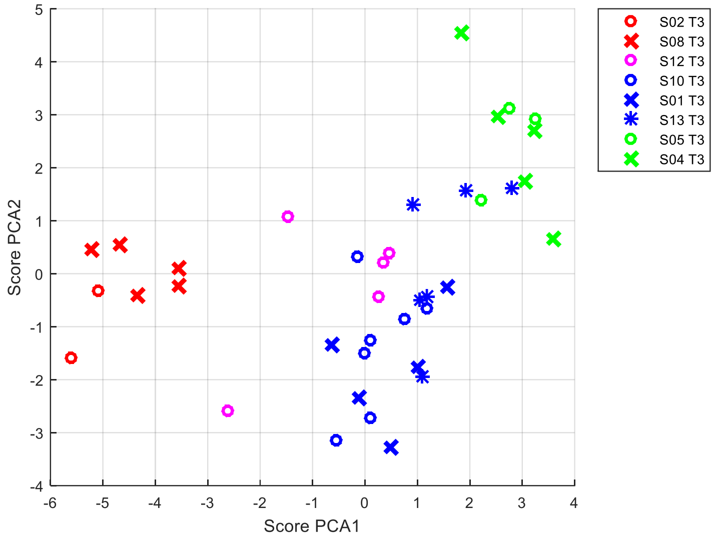


Figure 5-15. Scores of PCA1 (43% of variance) vs Scores of PCA2 (22% of variance) – (red: low skilled; magenta: intermediate; blue: advanced; green: expert)

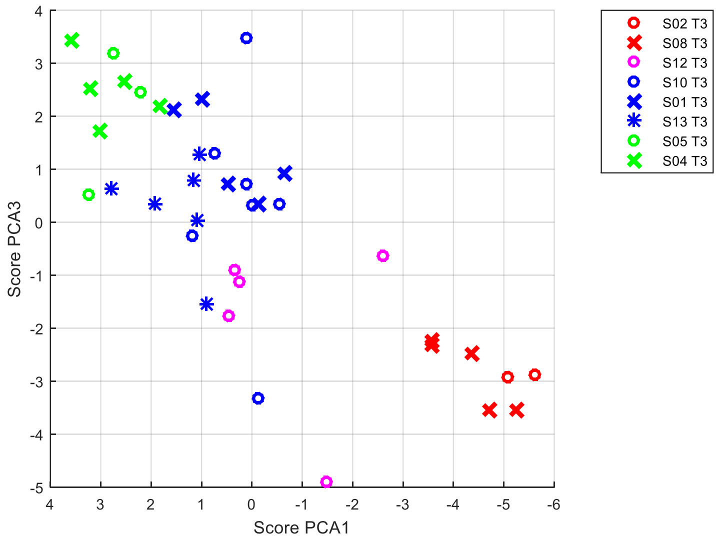


Figure 5-16. Scores of PCA1 (43% of variance) vs Scores of PCA3 (31% of variance) – (red: low skilled; magenta: intermediate; blue: advanced; green: expert)

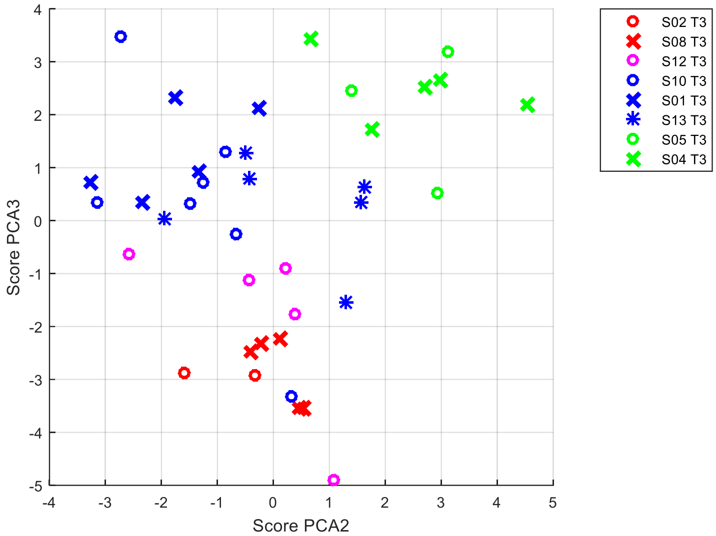


Figure 5-17. Scores of PCA2 (22% of variance) vs Scores of PCA3 (31% of variance) – (red: low skilled; magenta: intermediate; blue: advanced; green: expert)

5.3. Braking performance vs years of experience and skill self-assessment

The demographic data collected by questionnaire prior to the experimental sessions were used to establish an 'a priori' classification of skill in 4 levels, as presented in Table 5-9. The scale used for the self-assessment scores was as follows: 1-poor, 2-room for improvement, 3-adequate, 4-good, 5-very good, 6-expert.

Table 5-9. Summary of the demographic data and self-assessment by subject

Demographics				Self-assessments			
ID	Gender	Age	Experience (yrs)	Skill Level	Safety	Hazard perception	Braking
1	M	27	10	Very experienced	2	4	3
2	F	41	2	Inexperienced	2	2	1
3	M	24	7	Very experienced	6	6	6
4	M	26	10	Very experienced	6	6	5
5	M	23	7	Very experienced	6	6	6
6	M	47	31	Expert	2	4	3
7	M	39	19	Experienced	4	5	4
8	F	29	11	Experienced	2	4	2
9	M	40	21	Very experienced	5	4	5
10	M	24	8	Experienced	4	5	4
11	M	24	6	Expert	5	5	4
12	M	30	13	Very Experienced	4	5	4
13	M	45	-	Experienced	4	5	4

The correlations between mean effective deceleration and years of experience and self-assessed measures of skill are shown in Table 5-10.

Spearman's rho tests revealed that effective deceleration did not correlate with either number of years of experience riding or self-assessed overall skill. However, there was a strong positive correlation between effective deceleration and self-assessed hazard perception. There were medium positive correlations between mean effective deceleration and both self-assessed braking and self-assessed safety.

Table 5-10. Spearman's *rho* tests correlation for self-assessment and effective deceleration

		Effective Deceleration		
		rho	**CI_{95}**	***p***
Experience (years of riding)		-0.16	[-0.65, 0.43]	.627
Self-assessed	**Overall Skill**	0.18	[-0.37, 0.66]	.564
	Safety*	0.66*	[0.17, 0.89]	.015
	Hazard Perception**	0.84**	[0.54, 0.95]	.000
	Braking*	0.66*	[0.16, 0.89]	.015

** p < 0.01; * p < 0.05

The results revealed that riders' actual emergency braking performance was not related to their years of riding experience or how skilled they believed they were overall. Rather, demonstrated skill in emergency braking was closely related to riders' self-assessment of their expertise in safe skills and the two component skills – perception of traffic hazards and braking. These results suggest that riders have good awareness of their skill in detecting and responding to an emergency situation, but this may bear little relationship to their years of riding experience or self-perceived overall skill - an important distinction given that years of experience is a reference commonly used for licensure. Thus, we caution that a rider's assessment of their own skill and safety in more global terms is not a reliable indicator of his/her ability to stop quickly in an emergency situation. One explanation for this result is that riders take into account multiple component skills when determining how skilled they believe they are, but that the skills on which riders base such overall assessment are not the critical skills involved in responding to emergency situations. This finding has important implications for the prescription of rider training. While advanced riding courses are available, riders may not choose to participate in such courses if they believe that their existing level of skill and safety is already sufficient.

5.4. Model of braking performance. Definition of key patterns

The regression model developed used six parameters related to the interaction of the rider with the vehicle to predict the braking distance with an initial speed of 50 km/h ($Dist_{50kph}$) following the equation (9):

$$Dist_{50kph} = \beta 0 + \begin{bmatrix} \beta 1 & \beta 2 & \beta 3 & \beta 4 & \beta 5 & \beta 6 \end{bmatrix} * \begin{bmatrix} Front\ Brake\ Max \\ Rear\ Brake\ Max \\ Time-to-Peak \\ Time-on-Peak \\ Skid-front-time \\ Skid-rear-time \end{bmatrix} + \varepsilon \qquad (9)$$

The sample selected for the multi-regression model were all the braking trials with effective deceleration higher or equal to 4.5m/s^2 (145 cases), since the model aims to predict the emergency braking distances. Thus, 12 cases were effective deceleration were lower than 4.5m/^{s} were considered outlier not representing a typical emergency scenario. Consequently, the cases of the rider from group "A – Novice" were limited to a few trials. Cook's distance values from this model were calculated to find the cases that could distort the accuracy of the model additionally. Cook's distance with values greater than 4/n (in this case 4/145 or 0.0276) are considered high influence and may be considered a cut-off point. Cook's distance higher than 0.030 was the criteria selected to exclude the cases that distorted the model. After that, using 133 emergency braking trials, the refined final regression model improved with a coefficient of determination adjusted R^2=0.885. The results of the final model are presented in Table 5-11 and Table 5-12 and represented in Figure 5-18.

Table 5-11. Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.945[a]	0.892	0.885	0.79461

a. Predictors: BrakeF Mx, BrakeR Mx, Time-to-Peak, Time-on-Peak, Skid-front-time, Skid-rear-time, β_0 (Constant)

Table 5-12. Regression model Coefficients (dependent variable $Dist_{50kph}$)

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	β_i	Std. Error	β_{std}		
β_0 (Constant)	17.890	1.200		14.904	.000
BrakeF Mx	-0.126	0.009	-0.733	-13.991	.000
BrakeR Mx	-0.001	0.010	-0.001	0.146	.884
Time-to-Peak	2.931	0.421	0.277	6.959	.000
Time-on-Peak	1.375	0.415	0.170	3.310	.001
Skid-front-time	-1.104	0.311	-0.149	-3.544	.001
Skid-rear-time	1.581	0.861	0.078	1.835	.070

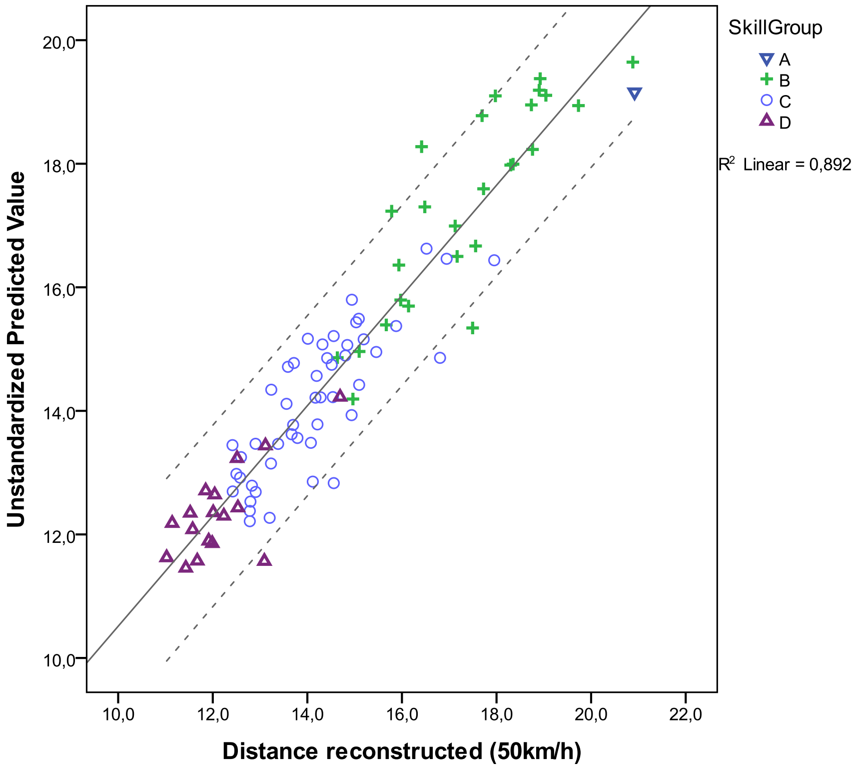


Figure 5-18. Scatter plot distance estimated (axis X) vs distance (axis Y). Fit lane of the model with CI95 . Predicted values

The final model is limited by the variance of the participants of the study that represents the input, especially by the number of experts found. Although the sample size is limited, it represents a wide spectrum of different levels as has been showed in section 0. Experts' patterns will represent the goals and the base of the feedback/training tool for the less skilled riders. It has to be noticed that the accuracy of the model will be representative of the emergency braking test in straight line with dry asphalt, and extrapolation to other scenarios may produce higher errors.

5.4.1. Braking Pressure

The boxplots of Figure 5-19 indicate the clear differences among groups concerning the use of Front brake and distribution of brake power Rear/Front. The higher the performance of the group the higher intensity in the use of front brake and the more predominant the front brake is in the brake distribution (low values for 'p' ratio: *Brake_Press_Rear/[Brake_Press_Rear + Brake_Press_Front]*).

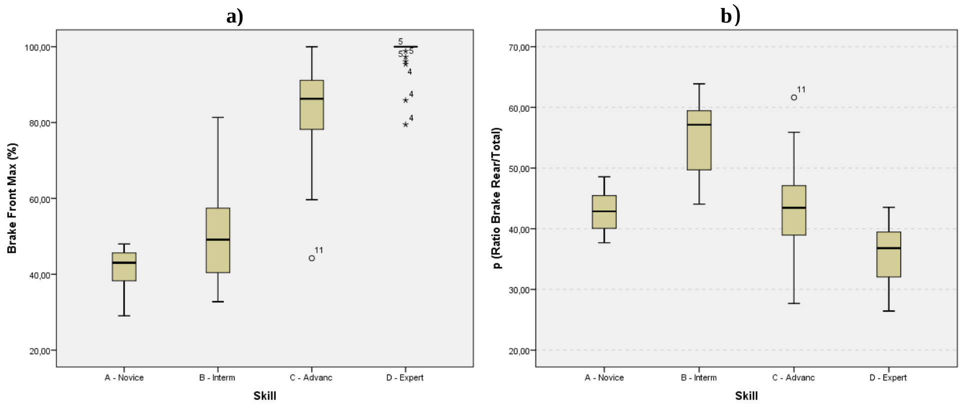


Figure 5-19. Box-plot by skill groups: a) Brake Front Maximum; b) 'p'(%) : Brake Pressure Rear/Total Brake Pressure)

The big differences in the use of the front brakes indicate that maximum front brake pressure is the main difference between lower and higher skilled riders. The results of the tests suggest that braking distance is mainly about the force applied by the particpants on the front brake lever. Thus, a low skilled rider could achieve a good braking performance focusing on the use of the front brake and the control of the unstability of the vehicle as a consequence of the higher decelerations. Figure 5-20 shows an example of the time series brake signal of three riders with different profiles during the emergency braking test.

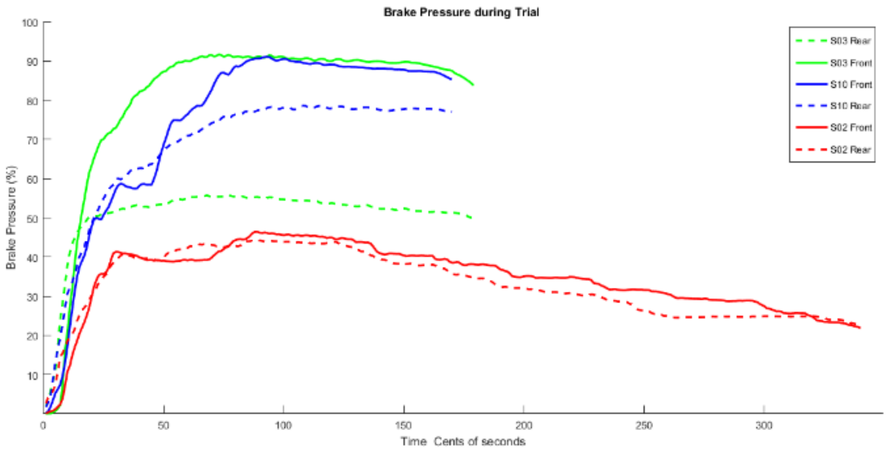


Figure 5-20. Example of brake pressure of three different riders during emergency braking test.

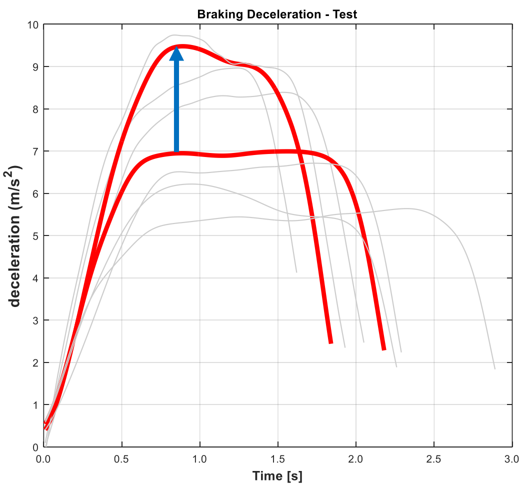
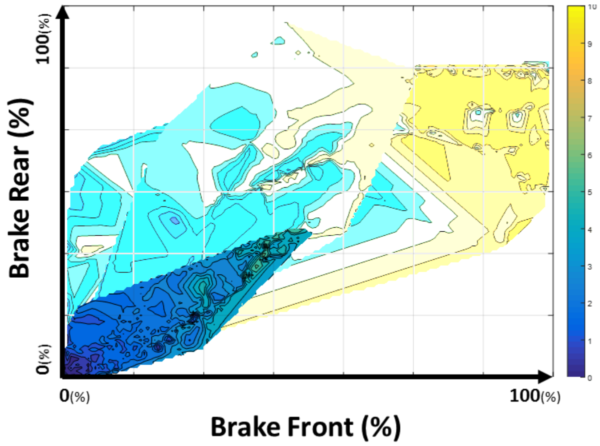
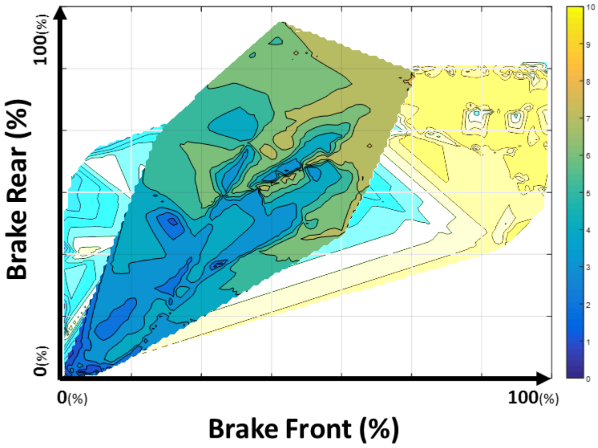


Figure 5-21. Comparison of Maximum Deceleration between riders ‘C-Advanced’ and ‘B – Intermediate’ (red lines)

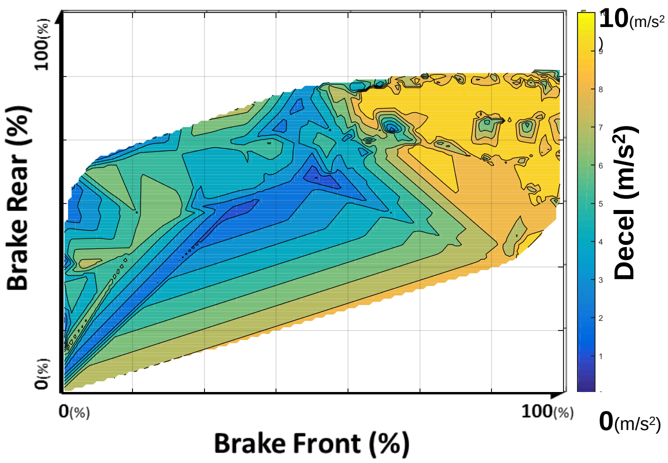
The maximum brake is directly related to braking deceleration and maximum deceleration. Figure 5-21, shows how although the initial jerk of the two signals representing deceleration of rider ‘C – Advanced’ and rider ‘B – Intermediate’ is similar, the maximum deceleration is clearly different. This can be seen in Figure 5-22 (novice, intermediate and expert) representing the map of the use of the brakes (from 0% to 100%) associated with the deceleration achieved represented in color (blue low and yellow high deceleration). The comparison of the maps among one rider from three different groups (novice, intermediate and expert) shows that novice and intermediate riders do not make a complete use of the front brake capability and consequently have a lower deceleration. On the contrary the expert rider uses the maximum of the front brake achieving peaks of deceleration close to 1g (yellow color).



A.



B.



D.

Figure 5-22. Use of brakes and deceleration: A) novice; B) intermediate; D) expert

5.4.2.Time to peak

Previous section has showed that the maximum pressure rate achieved is the most relevant parameter that differentiates the groups defined by braking skills. However, a descriptive analysis of the time to peak indicates that it is a parameter that mainly differentiate the expert riders from the rest of the riders. Expert riders values of time to peak are between 0.5 and 0.6 seconds (Table 5-13), what means a very fast activation of the brakes including high jerk and risk of locking the wheel at high speed. The rest of group of riders have values above 0.60 seconds. The low time to peak values found in the novice rider from group 'A' are related to the fact that is required a shorter time to achieve low peaks of deceleration. As far as novice rider increase the competencies to an intermediate level they will increase the time to peak.

Table 5-13. Time to peak (s) per Skill Group

	Time to Peak (s)				Riders	Trials
Skill Level	Mean	std. dev	CI_{95}		N	N
A - Novice	0.64	0.21	0.46	0.81	1	8
B - Interm	0.75	0.13	0.71	0.79	4	43
C - Advanc	0.73	0.18	0.68	0.77	6	73
D - Expert	0.55	0.11	0.51	0.60	2	25
Total	0.70	0.17			13	149

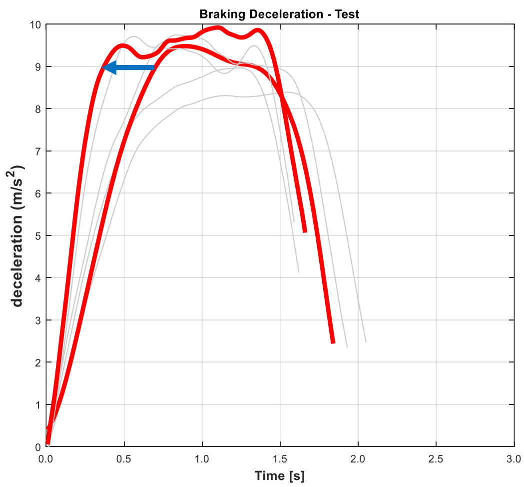


Figure 5-23. Red lines: Comparison of time-to-peak between riders 'B – Intermediate' and 'C-Expert' (red lines)

Figure 5-23 shows, as commented above, how expert and advanced riders have similar maximum deceleration and differ mainly in the time to-to-peak. This is an interesting finding considering that reaching the optimum braking in short time reduces considerably the braking distance. Advanced braking systems like ABS may be not sufficient to optimize the braking performance of riders with short time-to-peak that need to enhance the jerk in the first instants. New studies studying the time-to-peak with PTW equipped with ABS are suggested to test the validity of this hypothesis or otherwise to know if the higher time-to-peak is linked to the fear of less skilled riders of locking the front wheel.

Locked-Wheel: Maximum Braking gradient

It has to be considered that the time to peak cannot be too short (in case the rider was physically able to do it), since performing the tests with a non-ABS PTW it could lock the front wheel in the case the load cannot be transferred to the front wheel instantaneously, due to the suspension dynamics constraints (Corno et al., 2008). It is important to know where is the limit to push the riders to reduce the time to peak. For this reason the results of the tests with locked-wheel can give us a good reference about the minimum time_to_peak in terms of “effectiveness-PTW control”,

In a first approach with the ‘most aggressive’ front locked-wheel found during the tests, it has been found 460 bar/s as a value beyond the limit of PTW control. In the cases of S05 where Loss Control was observed during the experiments (and after with video analysis), the time to peak was around 0.4 seconds. This value may be considered as a very high risky value to lose control.

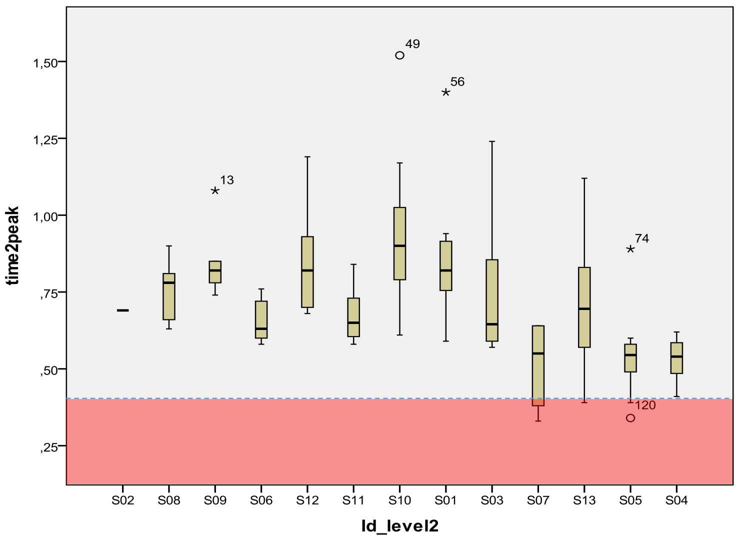


Figure 5-24. Box-plot of Time to peak (seconds) per rider ID.

Figure 5-24 presents the boxplot graph of time-to-peak per rider. The values that are in the red area are considered cases where the time to peak was too short with a risk of locking the front wheel at high speed and consequently lose the control.

5.4.3. **Conclusions**

The study has defined the key parameters to predict the braking performance with an accurate model. Maximum pressure in front brake and time to peak are the two most relevant parameters related to braking distance. In order to improve the braking performance, training activities should focus on optimize these key parameters. In the same way, advanced braking systems tailored for the competencies of less skilled riders, which are not able to utilise the full braking capacity of the motorcycle, could help to reduce their braking distance (for instance, enhancing the initial jerk and limiting the maximum deceleration achieved to avoid loss of control).

5.5. Braking Performance: Loss Stability Indicators

The signals from lateral acceleration, roll rate, steering rate, and the maximum slip factor were selected to define the model to describe the control of the rider on the stability of the vehicle. These signals were selected based on the results of a preliminary analysis of tests where it was perceived a loss of control. It was found that it was necessary to combine different parameters to understand the control of the rider since the prediction was not accurate based on one single parameter. For instance, expert riders can manage high lateral accelerations higher than 2m/s^2 that will cause a loss of control in the rest of the riders. It is difficult to know for experts if they still have the control or they are at the limit. After a principal component analysis (PCA) of different parameters derived from the four signals cited, the model defined was based on the parameters of Table 5-14.

Table 5-14. Parameters selected to define the model to predict loss of control

Signal (t)	Parameter	Description
Roll angle (deg)	Roll_decel_peak2rms	Ratio peak/rms of roll angular deceleration
Sttering angle (deg)	steering_rate_rms	RMS of steering rate
Slip factor	max_slip	Maximum slip in front wheel
Roll angle (deg)	Roll_decel_Max	Maximum of roll angular deceleration
lateral acceleration	accel_lateral_peak2rms	Ratio peak/rms of lateral deceleration

5.5.1. **Stability parameters from the PTW**

First a descriptive analysis was done with a random sample of riders to set the limits of the lateral acceleration. An initial threshold of 1.5 m/s^2 was set as the limit of control after watching controlled braking and some tests where it was found during the experiments (and validated by the video) that the rider was losing the control or close to it. For those cases it was found that the lateral acceleration was higher than the rest of the subsample selected, with values above 1.5 m/s^2 (Figure 5-25). However, after checking all the videos of tests that were over the threshold of 1.5m/s^2, it was found that expert riders were able to manage this lateral acceleration during the execution of the tests without signs of losing control, this was called 'limit of control' situations (Figure 5-26). Threshold between normal dynamics and a fall dynamics, due to the intrinsic unstable characteristic of the PTWs can be very thin (Cossalter, Aguggiaro, Debus, Bellati, & Ambrogi, 2007). It is difficult to know for experts if they still have the control or they are at the limit, but these values for a non-expert would clearly represent a loss control. Thus, it was necessary to use the combinations of different parameters to define a more robust model able to detect the actual loss of control of the riders without false positives and false negatives.

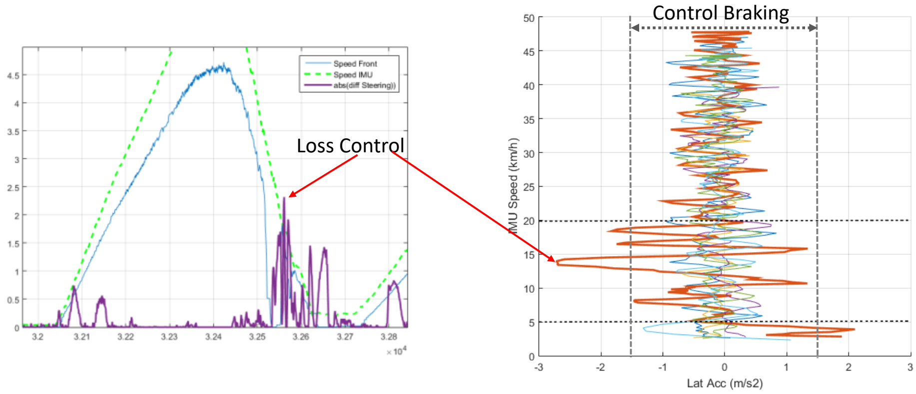


Figure 5-25. Example of advanced rider losing control with lateral deceleration>1.5m/s2

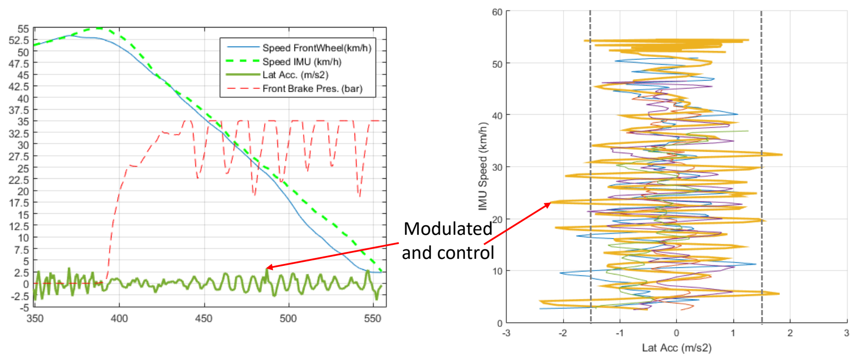


Figure 5-26. Example of expert rider in the limit of the control of the vehicle, managing lateral decelerations > 1.5m/s2.

5.5.2. **Logistic Binary Regression**

Based on the 12 tests observed (during the experiment and during video analysis) where there were signs of loss of control of the riders, it was defined a binary variable where ‘0’ was control and ‘1’ loss of control. A binary regression model to predict the binary variable was computed using the parameters previously selected of 105 braking trials. The results of the model are shown in Table 5-15.

Table 5-15. Logistic binary regression results for dependent variable Loss of Control

Variables in the Equation

	B	S.E.	Wald	df	Sig.	Exp(B)
Roll_decel_peak2rms	2.146	.944	5.172	1	.023	8.551
steering_rate_rms	15.973	17.083	.874	1	.350	8653412.935
max_slip	1.233	1.468	.706	1	.401	3.431
Roll_decel_Max	-.200	.357	.315	1	.575	.818
accel_lateral_peak2rms	.172	.738	.054	1	.815	1.188
Constant	-11.470	3.710	9.559	1	.002	.000

a. Variable(s) entered on step 1: Roll_decel_Max. Roll_decel_peak2rms. accel_lateral_peak2rms. max_slip. steering_rate_rms..

Table 5-16. Classification Table based on 0.5 of probability (P) as cut value.

		Predicted		
		Full Control	Loss of Control	Percentage Correct
Observed	Full Control	91	2	97.8
	Loss of Control	4	8	66.7
Overall Percentage				94.3

a, The cut value is 0.500

The model was able to predict 94.3% of the cases (Table 5-16) using a cut value of 0.5 of probability, where probability lower than 0.5 was considered full control and higher than 0.5 was considered loss of control. However, analyzing the values of the probability, it was found that the 2 cases of the 4 cases of loss of control observed that were not predicted by the model (false positive) were among the higher index of probability in the range 0-0.5 (probabilities of 0.21 and 0.39, see Figure 5-27). Similarly, the 2 cases predicted by the model as loss control with the lowest probability of loss of control were assessed as a full control braking by observation (probabilities of 0.51 and 0.60, see Figure 5-27).

As a result, the index of probability of the model represents a realistic predictor of the control of the vehicle, where it can be defined a third level between loss of control and full control in the range 0.20-0.61. The model of Probability of Loss control (*P*) will be defined as:

(P) = f (Lat Accel, Steering rate, Roll rate, Slip factor)

- Lossing control: $P > 0.61$
- Limit of Control: $0.20 <= P <= 0.61$
- Full Control: $P < 0.20$

Figure 5-27 represents the probability of loss control with the three types of control defined. The predictive model may help to detect when someone is on the edge of the control to warn the coach or trainee to keep the same (or even lower) level of deceleration without taking higher risk. The difference between less skilled and experts is large in these parameters. Less skilled riders have values frequently very far from the ‘loss control’ area while experts have a higher range on this ‘predictors’ than less skilled riders (see as an example Figure 5-27, expert riders Subjects *5* and *4* vs. intermediate riders Subjects *8* and *12*).

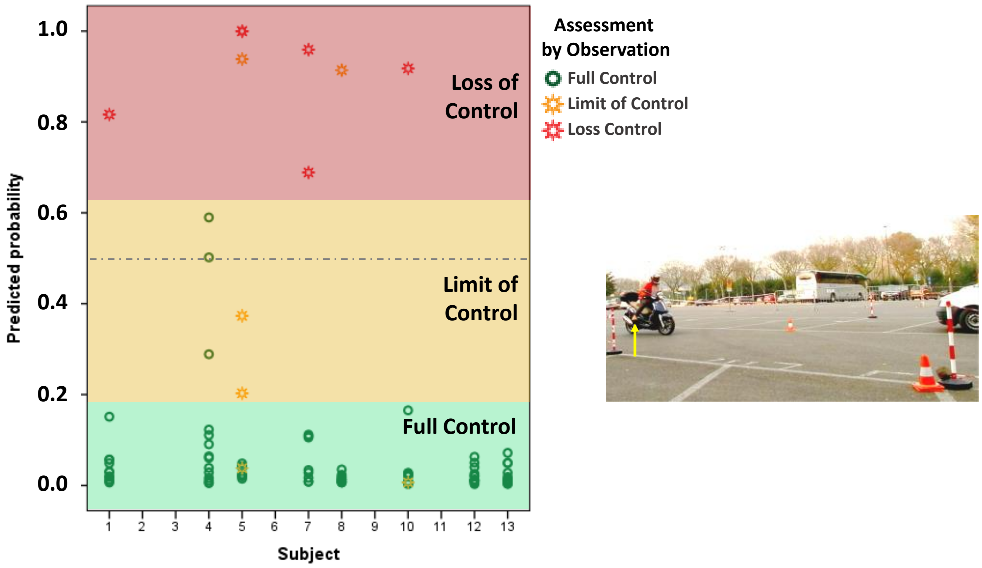


Figure 5-27. Index of probability of loss control of the different tests per subject. (where ‘1’= 100% of possibilities of loss of control, and ‘0’ = 0% of possibilities of loss control).

5.6. Total stopping distance: Response Time + Brake Action

Figure 5-28 presents the results of the average of stopping distance by subject using 50km/h as the speed before starting the braking manoeuver and the offset of 0.150s to the response time measures defined in section 5.1. The more the subjects are placed on the bottom right area the less the stopping distance and, therefore, the best performance of the rider during the test. Riders placed on the bottom area of the graph are considered with high skilled in perception, and riders in the right area are considered high skilled in braking manoeuvres. The lines crossing the areas represent the same stopping distances with a different combination control and perception skills. The map gives a complete view of the effect of the perception and control skills in braking distance. Riders with different profiles may achieve similar braking distances like S01 and S06. The map also shows that competencies in braking are not directly related to perception skill. An illustrative example shows how expert in braking manoeuvre S05 being less skilled perceiving the hazard presents similar stopping distance (around 17.5 meters) than S10 significantly less skilled in control manoeuvre but advanced perception skills.

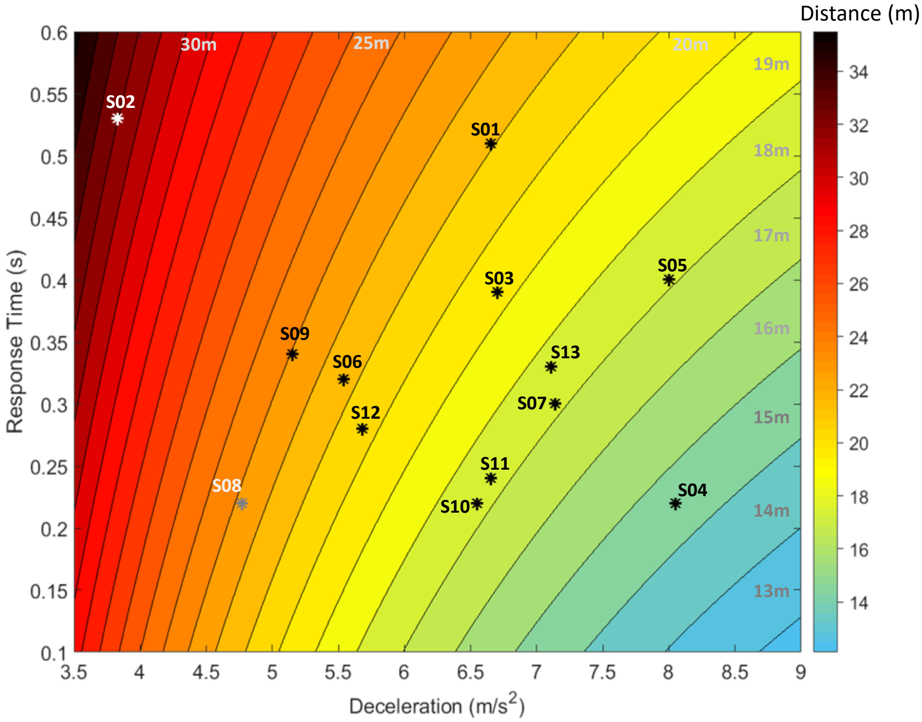


Figure 5-28. Results of Stopping distance per subject as a function of response time and braking deceleration

The procedure developed was successful to identify the competencies of the riders in perception and control skills (braking). The approach of this study goes beyond control skills assessment since central approach is performance in an emergency scenario. The test paradigm employed in this study addresses both the control skill for hard braking as well as the higher cognitive skill of hazard perception in traffic patterns. To improve at the real-world skill of emergency braking, these two components must be practiced in association, preserving the natural perception-action coupling, in order to develop the appropriate and specifics automatisms required braking in emergency scenarios for effective collision avoidance. Previous authors have cautioned that training for improved skill may produce overconfidence (Rowden & Watson, 2008) or sensation-seeking behaviour, that does not translate to improved safety (Savolainen & Mannering, 2007). By providing riders with objective feedback on such elements of their performance as disparity from target stopping distance, riders (including highly skilled riders) concern about their own limitation. Thus, this study and similar can be used to promote defensive riding indirectly, highlighting the importance of the effect of speed in hazard perception and braking distance under the approach to handling emergency is to prevent it in the first place.

5.7. Comparison between *Hard braking* test and *Emergency task*

5.7.1. Descriptive Analysis

A descriptive analysis of effective braking deceleration of the 33 hard braking trials performed by 11 of the participants that completed the hard braking test (Figure 5-29a) shows little difference between the three last emergency braking trials and the three hard braking trials. However, the boxplots of initial jerk (*jerk$_{ini}$*) from 0 to 4.5m/s^2 (Figure 5-29b) suggests a characteristic trend across riders for higher initial jerk during emergency braking test.

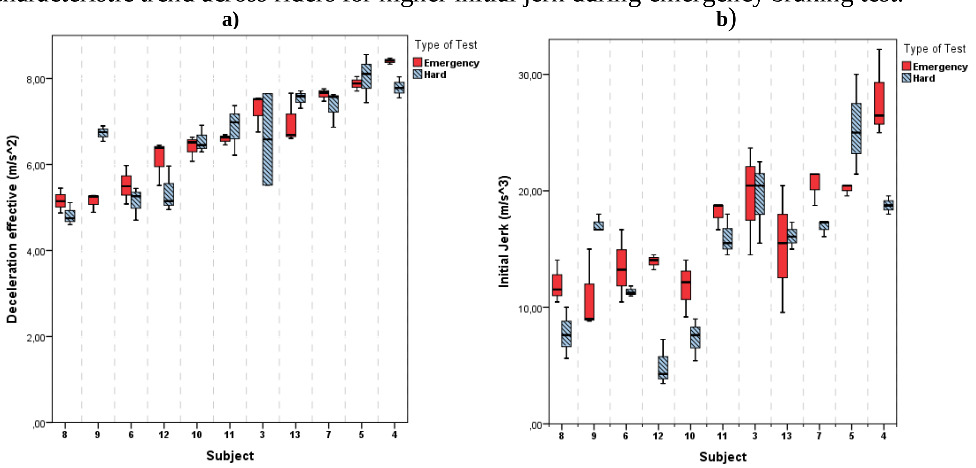


Figure 5-29. Box-plot for: a) effective deceleration dec$_{effective}$; b) initial jerk (jerk$_{ini}$)

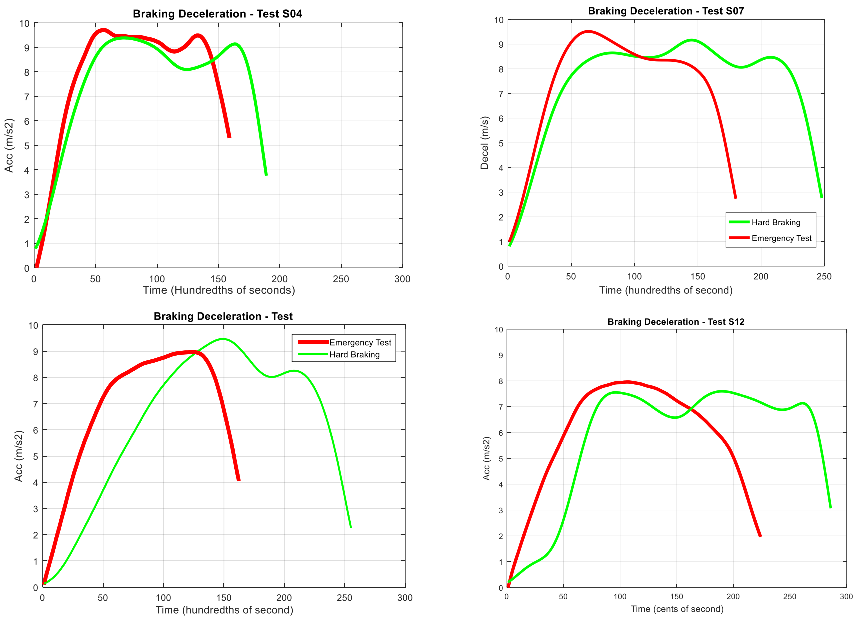


Figure 5-30. Example for four different riders with different skill levels

Figure 5-30 shows the characteristic curves of riders from different groups of skills (from intermediate to expert). In the figures it is easy to appreciate that there are different behaviours. In general terms, jerk was higher and time to peak shorter in the emergency test, what means that the main difference was that the rider was not preparing the moment to brake harder in a smooth way.

5.7.2. Analysis of the effect of the type of test with *Linear mixed models*

The results of the linear mixed model to test the effect of the type of test in the braking performance, confirmed that there was a significant difference in the scores between the emergency test and the hard braking test for $jerk_{ini}$ (p =.044). The results revealed that most riders exhibited higher initial jerk in a task where the brakes had to be applied after the perception of a motion cue not predicted (car turning in a randomized design) than in a planned self-initiated braking task (see examples of Figure 5-31). The linear mixed-model with the best fit was a random slope and intercept model that considered for the random factor *Rider* their different baselines and different slopes. There was not significant differences between the two types of tests for the other two variables $dec_{effective}$ (p =.379) and dec_{max} (p =.093).

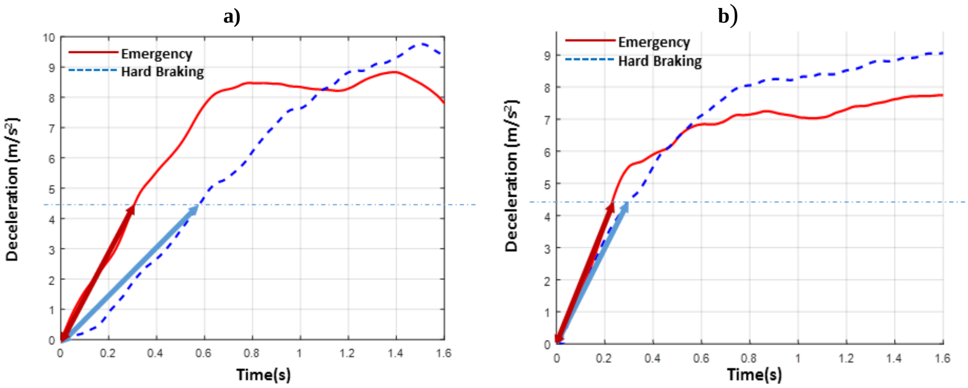


Figure 5-31. Comparison of $jerk_{ini}$ between emergency braking tests and hard braking test for Subject S10(a) and S11(b)

5.7.3. Conclusions

Comparing the performance of the emergency scenario designed with a more standard hard braking task, this research showed that there were differences in the way of braking in the initial jerk. The initial jerk of the riders after detecting an unpredicted hazard presence on the road (car crossing in front of the PTW) was different (mostly higher) than during planned hard braking test. Effective and maximum deceleration, however, were not affected by the type of braking task. One of the main differences in the procedure of the two type of test compared is the onset of the brakes activation (planned vs unpredicted), that is directly related with the first phase of the braking action (the one measured in $jerk_{ini}$). The differences in the $jerk_{ini}$ found suggest that the participants may behave closer to real emergency scenario in the first phase of the braking action performing the emergency task designed in this study. The review of Dilich et al., (2002) about driver response to a sudden emergency cites Thackray & Touchstone, (1983) to mention that emergency situations involves at least two phases, where first (shock phase) constitutes the initial reaction. The results suggest that the task designed induces an emotional arousal closer to this shock phase than conventional braking tests. The fact that the rider is alerted and knows that the car is not going to cross may make more similar the emergency test to a standard hard braking test in the last phase of the braking action. This is a significant finding, since it may be related to the fact that in crash imminent scenarios most riders change their braking pattern and may apply wrongly the force on the brake lever/pedal due to panic reactions (Sporner & Kramlich, 2001).

6. Interface with prescriptive feedback

6.1. Introduction

This chapter presents a training tool as a demonstrator of how the results of this research can be exploited. The tool will supply augmented feedback (i.e. adds sources of sensory feedback) to the rider with the relevant information from the characterization of the braking. The feedback will be provided in a nonverbal way in two different ways: a) knowledge of the results in form of braking distance and how far is from the optimum braking or the distance targeted (in meters and skill level); b) knowledge of performance providing information about the key parameters that will improve the performance modifying specific actions of the rider (e.g. increase the maximum intensity applied of the front brake or keeping the maximum intensity of the front brake for a shorter period to avoid to lock the wheel).

Figure 6-1. Diagram of the training process with feedback training tool

The feedback of knowledge of performance is based on the braking models of performance developed in chapter 5 that used the braking patterns of the 13 participants corresponding to different braking competencies. This diversity of braking behaviour makes reliable the model in the same conditions the test (dry and braking in a straight line) and with the same PTW.

Figure 6-2 presents an example of braking patterns with different performance in terms of deceleration and braking distance. The tool will use as reference the parameters that characterize the patterns of the expert riders. With this reference, less skilled trainees will receive real-time visual feedback on a screen (laptop or tablet) which will show them how their braking performance compares to the expert model. Simple graphics will show trainees not only what they are doing wrong, but also how to improve their braking performance. Figure 6-1 shows an outline of the training process of braking using the tool developed.

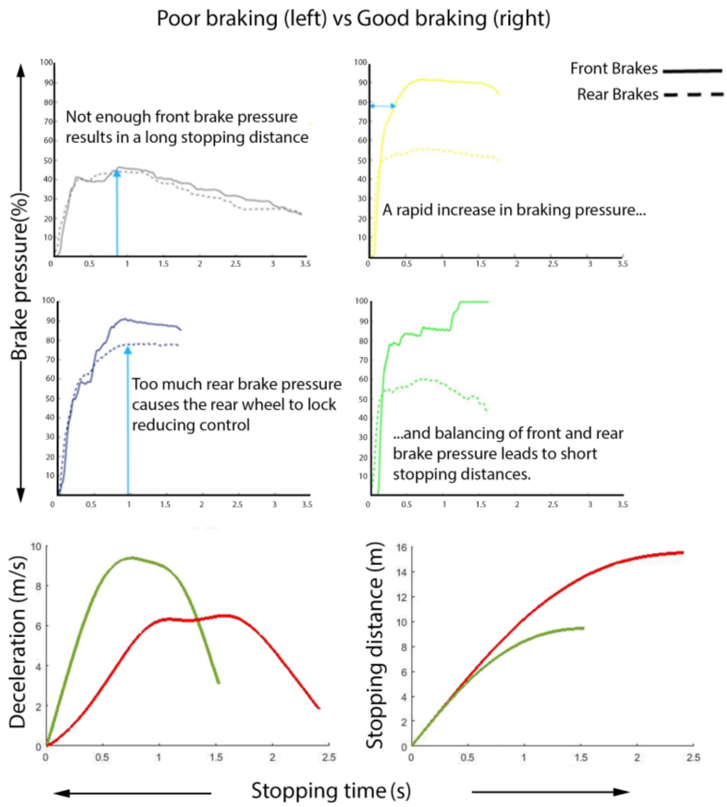


Figure 6-2. Example of comparison of 'good' versus 'poor' braking technique is shown in the top four line charts. The bottom charts show an example of how high skilled riders (in green) use good braking technique to decelerate faster (bottom left) and stop sooner (bottom right) compared to less skilled riders (in red). Source: (S. Rosalie, Huertas-Leyva, & Savino, 2016)

6.2. Training Tool Interface for Feedback

The interface of the feedback application has been developed with the GUI graphic application of Matlab ®. The aim of the design of the interface is to have a functional tool with the usability requirements needed to support the coach/instructor. Thus, the information provided has to be clear, accurate, easy to understand, and easy to be transferred to the trainee. The tool is divided in two different interfaces (Figure 6-3).

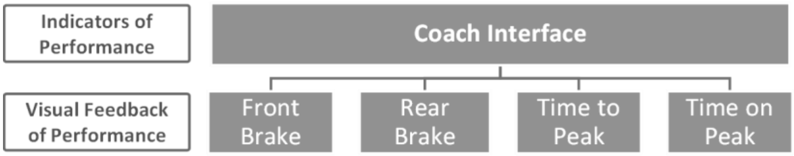


Figure 6-3. Diagram of the two different interface of braking performance

6.3. Coach Interface: Indicators of Performance

The main interface is the "Coach Interface", and provides a detailed information about the different parameters of the braking test performed. The indicators of the feedback interface (circle 1 in Figure 6.4) are the parameters key for an effective intervention, and are the same of the braking model developed (maximum pressure of front and rear brake, time to peak, time on peak, ratio rear/front brake, time locked rear and front wheel). For every parameter, the interface presents a matrix with three columns (circle 2 in Figure 6.4). The first columns represent the values corresponding to the test, the second column represents the value of the best braking performance from the model, and the third columns is a comparative of the two first columns in percentage. For example, if maximum pressure of the rider in front brake is 40bars and the best performance reference from the model is 50 bars the value in the third column will be 80% (40/50). The closer to 100% the better the action of the rider related to that parameter has been performed. The fourth column (circle 3 in Figure 6.4) corresponds to the estimation of the braking distance in case one the parameter fits with the value of the reference. The cell from the column with the shortest distance will indicate the parameter that more will improve the braking performance in case it is performed as the reference. These distances may be compared to the actual distance of the test performed (circle 4 in Figure 6.4). Finally, the interface has a field where the coach may estimate the reduction of braking distance by improving certain percentage (circle 5 in Figure 6.4). If the trainee is too far from the reference, the purpose is not giving a prescriptive feedback too demanding but increasing the level by small steps to assimilate the concepts on the safe side avoiding risks. In summary, the aim is to provide to the coaches the information to understand the weaknesses of the trainee, and guide them to focus on a simple instruction with the highest potential of improvement.

In addition, the interface provides information about average and maximum deceleration, velocity before braking and the control of stability of the vehicle during the test providing the probability of loss control using the model developed in chapter 5 (circle 6 in figure). In case the index of loss control is considered too high, the coach will ask to repeat the test more times at lower or similar level to get used to the dynamics of the vehicle at that deceleration before asking to increase the level. Based on all this information, the coach will select the most relevant parameter that the rider will need to improve, getting access this way to the feedback interface menu.

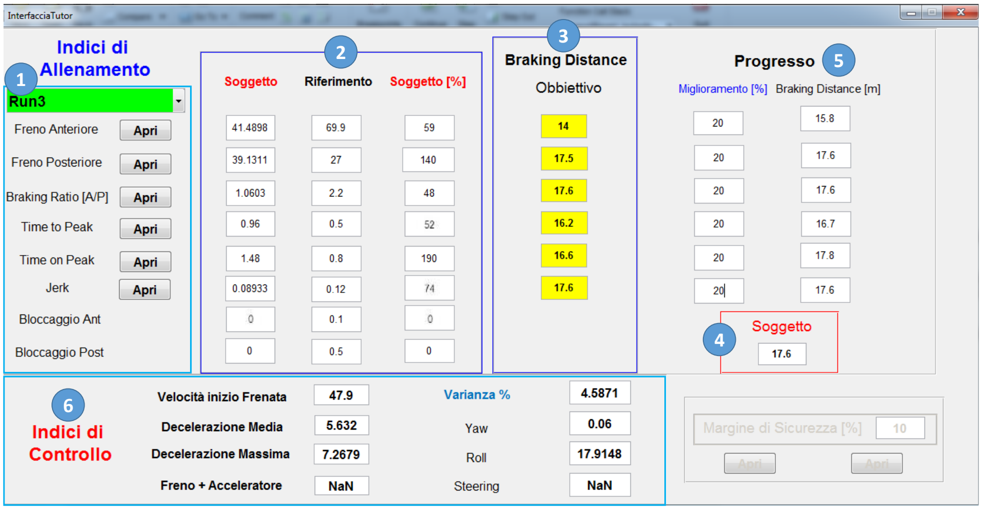


Figure 6-4. Coach Interface

The coach or instructor will be in charge to select the action to improve and the target level. Moreover, the coach will decide how long the trainee has to repeat the tests at the same level in order to consolidate and retain the learning stage acquired. The decisions of the coach will be based mainly on the progress of the trainee during the learning process.

6.4. Performance Indicators

After the selection of the parameter to improve in the Coach Interface, a second interface will appear with the prescriptive feedback. This second interface presents information about how to improve the braking performance quantifying the improvement in reduction of braking distance. The tool is designed to customize the training based on the trainee requirements. The interface shows a simplified chart presenting one of the parameters that the rider will modify to improve his/her performance. The parameters directly related to the instruction of the coach are those concerning action of the rider on the PTW, i.e. the brake pressure applied on the brake levers/pedal.

In order to provide a clear instruction to the trainees, the curves of the *braking pressure* are simplified to the response of a first-order system to step input (Figure 6.5). The time constant of the curve is the time that the input (brake pressure) takes to obtain the 63% of the maximum value with the same time constant and with the steady state value as the value of the parameter maximum pressure (front brake, rear brake and time to peak). For the *time to peak* the signal presented, as in the other cases, is simplified as a first-order system response with maximum amplitude constant and variable to modify is the time constant that in this case represents the 'time to peak' (Figure 6.6).

In the case of parameter *time-on-peak* a Gaussian distribution modified extending the maximum value for a period equal to the 'time on peak' of the parameter (Figure 6.7) is represented. In addition, the result of the braking distance in a scale with different levels (Beginner, Intermediate and Advanced) is presented.

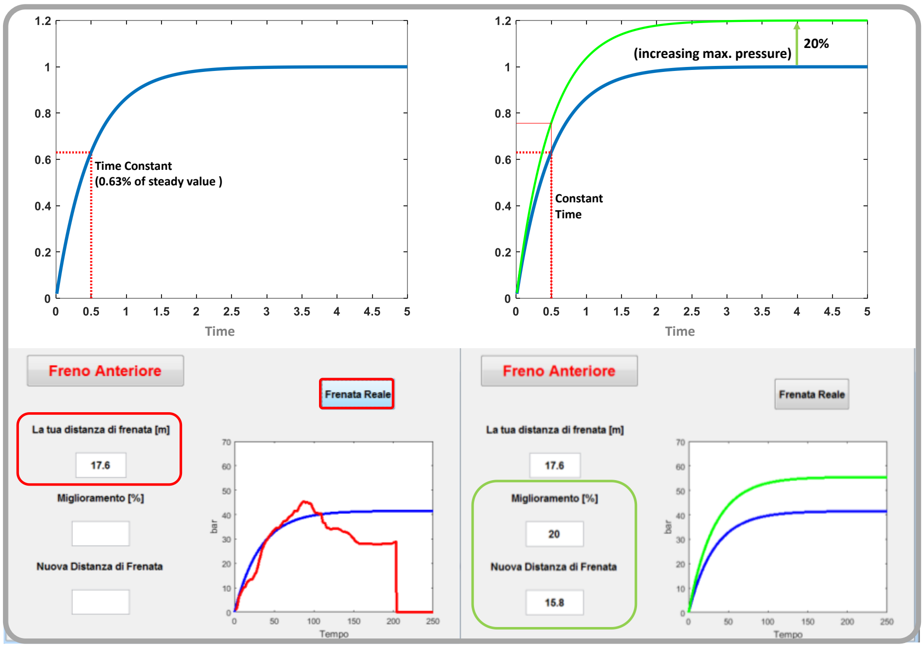


Figure 6-5. Visual feedback for Brake Pressure: Curve real (red), Curve simplified (blue), Curve suggested (green). Example of prescription of increasing the pressure intensity in 20% without changing any other parameter (e.g. time-to-peak).

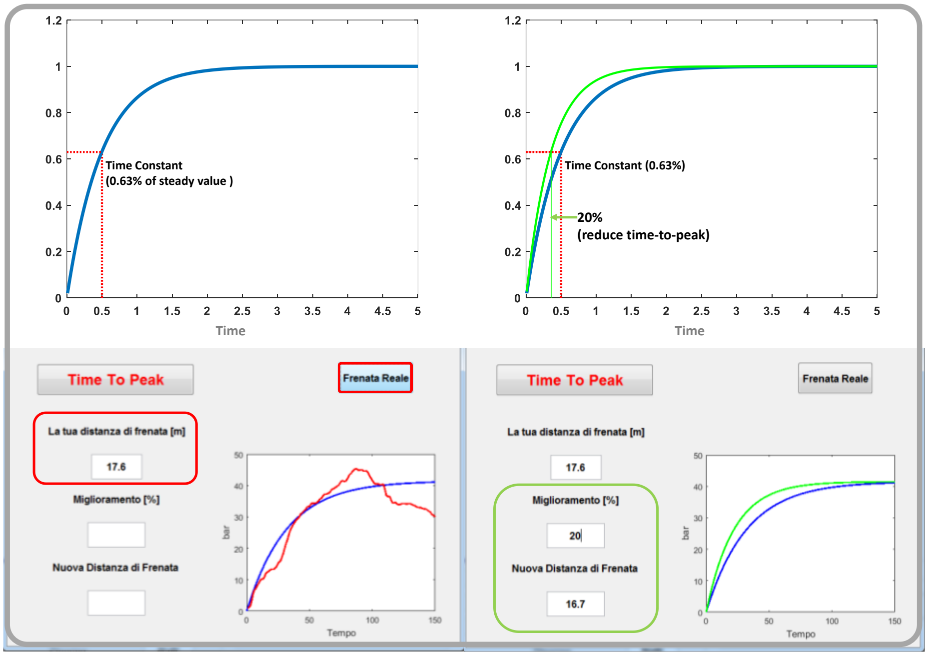


Figure 6-6. Visual feedback for Time-to-Peak: Curve real (red), Curve simplified (blue), Curve suggested (green). Example of prescription of reducing the time-to-peak in 20% without changing any other parameter.

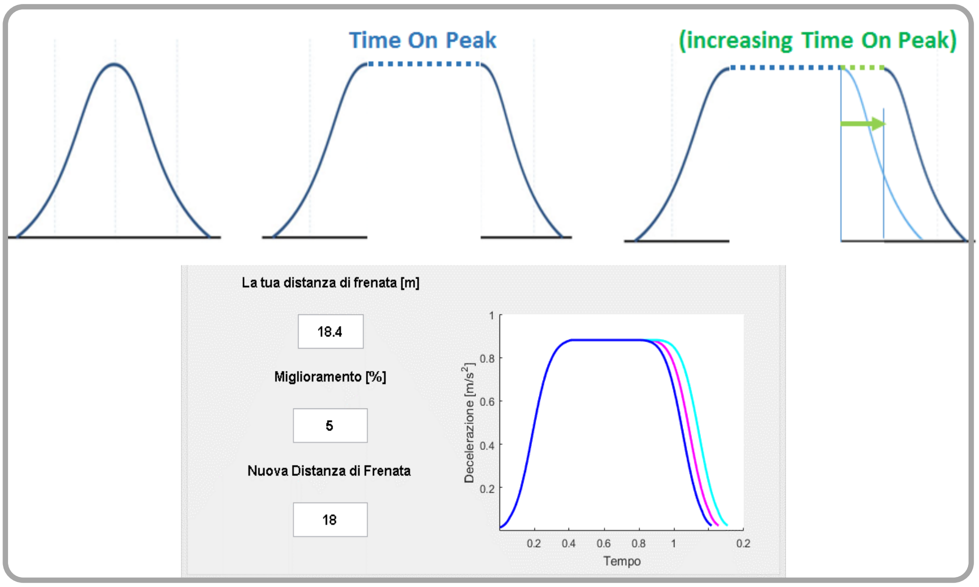


Figure 6-7. Interface with feedback to improve the braking modifying the timing of the braking pressure ('time on peak')

Because the data from the sensors on the scooter and the rider is processed and displayed immediately after riders have completed a set of braking 'drills'; every rider will receive personalised feedback as their learning progresses. Research has shown that this type of training is very effective in improving people's performance of skills in situations where they are under severe time pressure and have to predict the outcome rather than having time to think and act (Müller, Gurisik, Hecimovich, & Harbaugh, 2017; Williams, Ward, Smeeton, & Allen, 2004), just like what happens in emergency braking,

7. Conclusions and final remarks

7.1. Summary

The main aim of the PhD activity here presented is understand PTW's riders behaviours in risky scenarios, when the time to collision is too short and evasive manoeuvers are required. This research focus on the identification of the key components of control skills, together with perception skills, required for effective training interventions that can reduce the number of PTW collisions or mitigate their consequences

This PhD activity has devised a method to characterize the behaviour of the riders in emergency evasive manoeuvres performing braking in a task that integrates the perception and action. The work highlighted the need to understand the behaviour of the riders in emergency manoeuvres, and specifically braking, to define strategies that increase their safety reducing crashes and their fatal consequences.

The first stage of the research of this thesis analysed the lack of the skills linked to the most frequent crash scenarios using in-depth investigation of PTW accidents. The objective was understanding the main skills required to increase safety to be investigated and improved in the future. Combination of perception and controls skills were determined as the main competencies needed when facing an emergency situation. In addition, this in-depth accident analysis has found that emergency braking scenario is the most relevant evasive manoeuver and needs high competencies in perception and control skills. The results of in-depth accident analysis are supported by the literature review that reported that braking is the most difficult manoeuver to learn, and that many riders fail to perform it correctly during evasive manoeuvers. The analysis of the naturalistic data also revealed that some experienced riders seems to underuse the front brake performing hard braking. Additionally, riders' instructors from different regions of Italy were consulted with surveys to understand the braking training procedure and the instructor needs to define a procedure able to assess in an objective way the performance of the riders in a realistic scenario.

The research approach highlighted the need to measure and assess the behaviour of riders with different level skills (from novice to experts) in an emergency scenario to understand what (and how) the highly skilled riders do to reduce risk of collision compared to less skilled riders. Knowing strengths and weakness of the riders with objective and understandable parameters will help to provide rich and objective feedback and set targets for effective training.

The objectives of the research of this thesis, addressed in Chapter 1, are the following:

- Understanding the skills/competencies required to reduce accidents in most risky scenarios.
- Studying the behaviour and performance of braking as the most relevant evasive manoeuvre.
- Design of realistic scenario coupling hazard perception skills and PTW control for training.
- Definition of objective key parameters associated with the level of competencies during emergency braking.
- Quantitative characterization of the human riding skills applied to braking scenario.
- Development of an interface tool with objective feedback to support learning process

The proposed research identified multiple variables with an instrumented PTW and video cameras related to the perception-action task of emergency braking. The study assessed the perception skills of the riders measuring the response time of the different riders' profiles.

To identify objectively the performance differences among rider profiles in an emergency scenario, a field experiment was conducted in a real-world controlled environment. The test scenario was built in a parking lot with a car turning in front of the rider representing one of the most frequent crash scenarios and the most frequent scenario among those crashes with severe injuries. The scenario reproduced is also one of the scenarios where the perception-action task associated to emergency braking is critical.

The procedure developed was successful to identify the competencies of the riders in perception and control skills (braking). Three different categories of perception skill level and four of braking performance were defined. The threshold values of effective and maximum deceleration found that separates the different categories of level skills may be used as a general indication for the emergency braking tests.

The patterns of the riders' interaction with the PTW during the braking action were characterized in objective parameters. The patterns of the sample of riders of the research, that represented different competencies profiles, were used to make a model that estimates the braking performance as a function of the interaction of the rider with the PTW using the brakes. The braking performance is estimated in quantitative terms (braking distance) using regression models. Maximum brake pressure in front wheel and time-to-peak are the most important parameters linked to braking distance. The model developed may also identify the competencies of the riders in qualitative terms using the four groups of skill levels found during the study. In addition, the cases where it was perceived during the experiment and video analysis that the riders were losing complete control of the vehicle, were used to create a model that predicts the loss of control. This model was possible due to the realistic scenario designed, where riders were in a safe environment but reacting as in a real emergency situation (pressing abruptly the brakes experimenting high jerks or locking wheels). As a demonstrator of the potential of the findings of the study, it was designed a user interface to assess the braking performance and provide prescriptive feedback.

The approach of this study goes beyond control skills assessment since central approach is performance in an emergency scenario. Thus, this study and similar can be used to promote defensive riding indirectly, highlighting the importance of the effect of speed in hazard perception and braking distance under the approach to handling emergency is to prevent it in the first place.

7.2. Thesis contribution

The research presented in this thesis contributed to the knowledge in the fields of road safety and human factors. This section presents the contributions of this research.

7.2.1. Study of riding behaviour using in-depth accident cases and naturalistic studies

The first contribution of this research to the road safety field has been the identification of the lack of the skills in real cases accidents associated to specific scenarios. This research used in-depth accidentology data to understand the behaviour of the riders in the most critical scenarios. The thesis shows the direct relationship between the most frequent lacks of skills associated to the most frequent scenarios.

The second contribution is the confirmation that the PTW riders do not have a universal knowledge of the proper use of the brakes. This finding is also extended to cyclists on e-bikes. The analysis of naturalistic studies has found a relationship between the use of brakes during soft routine braking and hard braking, i.e. predominant use of the rear brake or of the front brake during routine braking was related to predominant use of the same brake (rear or front) during hard brakes. The evidence presented highlights the importance of practicing with the right brake distribution (front/rear) to create automatism that increase the performance of the braking manoeuver and reduce the response time.

7.2.2. Real world scenario

Lack of realism environments (i.e. lack of the complexity of the real world) have been detected as one of the main issues of the current training. The common scenarios used during training are mostly not sufficient to assess the ability to safely ride in traffic. This research has defined a real-world controlled scenario to identify and assess the competencies of the riders in an integrated perception-action task like the emergency braking evasive manoeuver. The scenario and procedure has been validated as a successful method with different types of PTW to identify the competencies of the riders. Thus, the research provides a method to assess the performance of the riders in a consistent and realistic way. Nevertheless, it has to be noticed the complexity to conduct this kind of test, including a car and a trained driver, inherent risk requiring full control of the test procedure, and an instrumented PTW. Thus, an implementation of the proposed approach at larger scale will have to deal with the mentioned complexity.

7.2.3. Objective key parameters associated with the level of competencies

Perception Skills

The response time during braking manoeuver has been studied in previous researches mainly using lights or screens that indicates the start of the braking. These methods allow to have an accurate way to identify the onset of the stimulus, so the measures of the response time give a good approach to capacities of the rider to react with simple stimulus (light on/off) and makes that measures easily comparable. Although these tests integrate somehow the perception-action of the braking task, they are far from a real-world situation where the rider needs to scan, evaluate and predict dynamic cues with multiple parameters (speed, position, distance, trajectory…). The scenario designed for this study represents a faithful situation where the rider has to evaluate complex stimulus continuously changing increasing the cognitive load closer to real world riding. During the practice of the experiment, the riders not only increase their motor agility to response after detecting the hazard, but also learn to scan and interpret the main cues linked to the onset of the hazard. The test was designed to introduce the emergency braking scenario in an unpredictable way. The emergency situation was not unexpected, though. The participants knew that when getting close to the intersection there was a high probability of emulate an emergency braking manoeuver. As far as the rider was doing more trials (to a maximum of 27 trials), the rider was more familiar with the scenario, the key cues were more clear, and the less information had to be processed. As a consequence, intermediate perception skilled riders reduced in a significant way the reaction time in the last round of trials. The most advanced riders in perception skills detected the key cue in the very first trials and they kept the high level during the rest of the experiment. The novice rider did not experienced any significant improvement during the whole experiment since the cognitive load of the rider was mainly focused on actions related to the control of an unknown vehicle. The study has found that the higher skilled riders were able to predict that the car will turn before the car was actually turning, using some other cues (e.g. the car velocity).

Repeating frequently an exercise related to response time coupled with an action (braking) in a realistic scenario, will generate automatism that may help when it comes a real emergency situation to react quicker and processing less information. The advantages of the scenario with a dynamic cue as realistic tool for training emergency braking become a limitation for quantifying the onset of the hazard in an accurate way that can be compared to the results of the conventional methods using motionless target to check (as a light or screen panel).

This research differs markedly from previous studies on braking with regard to the extra workload demanded of the riders, since they were required to perceive and predict the movements of an opponent vehicle. Indeed, it has been found that using the indicator before the turning (that was actually a distracting component) has a negative effect in the braking performance (reducing de deceleration rate) mainly for the less skilled riders. The use of distraction elements on purpose may compensate for the lower level of complexity of the simulated field experiment compared to real world. Future researches about learning effect of the riders may study if the effect of a distracting components is just significant during first stage of the training and can be overcome afterwards.

Braking performance

The aim of defining indicators able to classify different skill levels in braking performance was achieved by analyzing effective and maximal deceleration. The results allowed definition of four different levels of skill, with 7.28 m/s^2 as the CI_{95} lower limit of effective deceleration for expert riders and 8.0 m/s^2 as the maximum deceleration that differentiates expert and very experienced riders from less skilled riders.

This study differs markedly from previous studies on braking with regard to the extra workload demanded of the riders, since they were required to perceive and predict the movements of an opponent vehicle, and not simply respond to a static light. Indeed, it has been found that using the indicator before the turning (that was actually a distracting component) has a negative effect in the braking performance mainly for the less skilled riders.

In addition this study has explored the analysis of the time series signal of deceleration during the braking test as a complementary way to analyse the patterns of the different riders. The functional data analysis has decomposed the characteristics of the braking response as a combination of three independent functions related to intensity, rise time and length of the peak.

Finally this research has shown that the highest skilled riders in the action braking are not necessarily the riders with the highest perception skills. The study highlights the importance of the acquisition of both skills to reduce the risk of a collision.

Self-Assessment vs Objective Performance

A complementary analysis examined the relationship between years of experience or self-assessment and objective measures of PTW riders' skill in perceiving traffic hazards and braking in a real-world situation. The results reveal that riders' actual emergency braking performance was not related to their years of riding experience or how skilled or safe they believed they were overall. Thus, it is suggested that riders' self-assessment of more global measures of skill is not a reliable indicator of their ability to stop quickly in an emergency situation. One explanation for this result is that riders are taking into account multiple component skills when determining how skilled they believe they are, but that the skills on which riders base such overall assessment are not the critical skills involved in responding to emergency situations. This finding has important implications for the prescription of rider training. While advanced riding courses are available, riders may not choose to participate in such courses if they believe that their existing level of skill and safety is already sufficient.

It was also found, riders' self-assessment for skill in visually detecting traffic hazards and braking was closely related to the deceleration rate achieved in response to the hazard posed by a car executing a left turn across their path (an LTAP/OD event). Critically, the strongest correlation was found between deceleration rate and self-assessed hazard perception (rho=0.76). This supports a previously reported link between higher order hazard perception and situational awareness skills in accident rates (Beanland, Goode, Salmon, & Lenné, 2013). Moreover, combined with the evidence reported here that the ability to decelerate rapidly as avoiding maneuver after perceiving an imminent collision IS NOT related to experience, these results suggest that deliberate practice of collision perception and avoidance though training may be valuable in reducing collision rate.

7.2.4. Characterization of the human riding skills applied to braking

The study identified the key parameters associated with the performance of the braking manoeuver. Maximum brake pressure in front wheel is pointed as the main parameter of the interaction of the rider with the PTW action that makes the differences between less skilled rider and higher skilled riders. In addition, rise time (time to reach the first peak deceleration) was identified as the parameter that distinguish the expert riders. Expert riders reach the peak deceleration in the shortest time, getting close to the limit of the front wheel locked. A model to estimate the braking performance of the rider is developed. The model provides information with the steps required for a gradual improvement from novice to expert.

In order to assess the control of the vehicle during the braking maneuver and avoid pushing to the riders beyond their limits, the thesis provides a model to assess the control stability of the vehicle. The two models developed are implemented in an interface tool with visual graphs that classify the skill level of the rider and provide prescriptive feedback to support learning process. Improved braking skill will mean riders will avoid collision or reduce injury severity by perceiving hazards earlier, braking sooner and in a shorter stopping distance.

7.2.5. Contribution for the design of safety systems

Additionally, the identification and characterization of different rider profiles may support future design of active safety systems. The research has found that different rider profiles can control the vehicle with different decelerations. In the case of the development of Autonomous Emergency Braking systems (AEB) this finding is critical. The threshold of 8 m/s^2 of peak deceleration found, that clearly separates the group expert and advanced riders from intermediate and novice riders, may be considered a significant cue in this aspect. This study reveals that the optimized AEB system could be tailored to the competencies of the rider, since decelerations that may bring to loss control of less skilled riders may be undersized for high skilled riders. In addition, the model that predicts the loss of total control of the vehicle using the data collected during the experiment reveals new findings that may be integrated in the development of stability control systems. Finally the study has found evidences that some low skilled riders are not able to use the full braking power of the vehicle, and that most of the riders need to reduce the time-to-peak increasing the initial jerk. Less skilled riders may need specific training to be confident to use the full braking power of the PTW, otherwise some safety features of the PTW may result useless.

7.3. Limitations

The assessment of the emergency braking is valid for straight line emergency braking with high friction on the surface of the road. The sample of riders is limited to 13 riders, although this sample represents very well different competencies as has been showed. Experienced motorcycle riders without experience riding scooters may have shown lower deceleration results in the tests than they would have on a motorcycle, considering the necessity to adapt to a different geometry and brake activation configuration (rear brake controlled by left hand instead of right foot), which could reduce automaticity and increase cognitive load of the task.

The PTW instrumented of the experiment had standard brakes with no ABS or CBS systems. This may be considered a limitation of the study considering that ABS has been revealed as an effective safety system in emergency scenarios, and that an increasing number of countries, such as those members of the European Union or Japan will soon be mandating motorcycle ABS as standard equipment by legislation. Nevertheless, the fact of using PTW without ABS, or other kind of advance braking system, helps to have a full understanding of the actual behaviour and competencies of the rider interacting with the vehicle. Measuring with PTW equipped with ABS would give relevant information about the different performance of riders, but the mapping of the brake system would limit the practice of the rider to act beyond the limits of the frame of an advance braking system that modifies the actual inputs of the riders. For instance, conservative configuration of the ABS would avoid to know the stability control limits of the most advanced riders and the input required by the rider to control the vehicle. Understanding the behaviour of the riders from the experiments with a nonABS/nonCBS PTW may also reveal new insights for new safety systems and re-definition of braking systems (f.i. tailored ABS, tailored autonomous braking system).

In spite of the contact with different riding schools during the project, the sample of novice riders was limited to one, due to the difficulty of recruiting novice riders that meet all the study criteria in the test location area (Florence, Italy). Specifically, since a significant proportion of Florentines begin riding at age 16 after obtaining A1 licence (for riding PTWs up to 125 cc with maximum power of 11 KW) and upgrade to larger PTWs over 18 with A2 licence, it is very difficult to find new riders with a license permitting them to ride PTW with engines larger than 125 cc. The model of braking performance has been implemented with specific conditions (i.e. emergency braking in straight line) to have a high accuracy for the aim of the study. Thus, its application is limited to these conditions and it is not valid as general model behaviour for other type of braking (e.g. cornering). The model may be refined for more generic applications with field operational tests where the riders perform braking manoeuvers in different conditions.

7.4. Recommendations for further work

7.4.1. Field Operational Test and Naturalistic Studies to identify riding style and behaviour

Future studies should include Field Operational Test (FOT) in urban circuit with the same 13 riders that participated in the test with scooter PTW. One of the positive aspects of the FOTs, if the design includes similar conditions (traffic, light and weather), is that data can be compared directly between the participants. Thus, the riders' performance obtained with emergency braking tests could be crossed with their riding style (aggressive, cautious) using the data from lateral and longitudinal acceleration and analyzing their G-G diagrams. The route of the urban circuit would cover a wide range of manoeuvers including scenarios where the riders need to brake (stop signals, traffic lights, roundabouts and pedestrian cross) and three laps to compare the consistency of behaviour.

In a more ambitious approach, naturalistic studies with the same riders could complement the study of this thesis. Data from hard braking cases and particularly data from near misses events requiring braking as evasive manoeuver would reveal insights about the relationship between the performance of the emergency braking test and the behaviour of the riders in real-life events. As this work has showed, concerning the control of the vehicle, different profiles of riders are linked with different threshold of maximum deceleration as well as different threshold of stability parameters (lateral deceleration, steering rate…). This identification per subject may help to customize the algorithm to detect critical events per rider increasing the rate of cases found and limiting the false positives and false negatives associated to this kind of analysis.

7.4.2. Training Intervention

The outcomes of this study will provide both methodological guidelines and data comparisons for future studies on training. This thesis has identified the braking patterns of different skilled groups (novice, intermediate, advanced and expert) identifying the parameters that most contribute to achieve the higher decelerations during hard braking. This study provides a solid base to define a new training method including specific quantitative parameters for the calibration of such method. Ericsson et al. (Ericsson, Krampe, & Tesch-Romer, 1993) defined the extended deliberate practice as the training activities most closely associated with consistent improvements in performance. The procedure defined for the test of this research may be used to train riders with deliberate practice in emergency braking. Ericsson (Ericsson, 2004) found in his review of studies of learning and skill acquisition that there is evidence for consistent gradual improvement of performance if the following three components are considered: a well-defined task; an immediate detailed feedback; and the opportunity for trainees to perform same or similar task repeatedly to improve their performance progressively. The research of this thesis has set the first two components with a well-defined emergency braking task coupling perception and action in a controlled real world scenario and with a tool to provide visual feedback of the performance. Future work will address a longitudinal study to investigate the progress of the trainees during several emergency braking sessions as training method. In order to measure the actual effectiveness of the training, it will be necessary to study how the skills acquired during the tests are transferred to real world and how these skills are retained along the time.

7.4.3. Applications for Riding Schools

In order to export the method of this study to a broader application used in driving schools it is necessary to make the technology used in the experiment more accessible (Figure 7-1). The sensors included in the smartphones (accelerometers, gyroscopes and GPS), although more limited and less reliable, represent an accessible alternative. Measuring the performance with smartphone's sensors will lack the measure of the use of the two brakes that have been the main variables to understand in rider-PTW interaction. Further work is suggested to predict brake actions on the two wheels with methods like neural networks with supervised training providing accelerometers and gyroscopes signals as inputs and brake pressures as outputs.

One future application is to use the procedure and this study in riding schools initially with the same type of PTW to have a database of the patterns of pre-licensed and novice riders to understand better their behaviour and to validate the method. At the same time, the implementation of the training tool (e.g. using a tablet) with low cost sensors will spread the tool to riding schools much more widely.

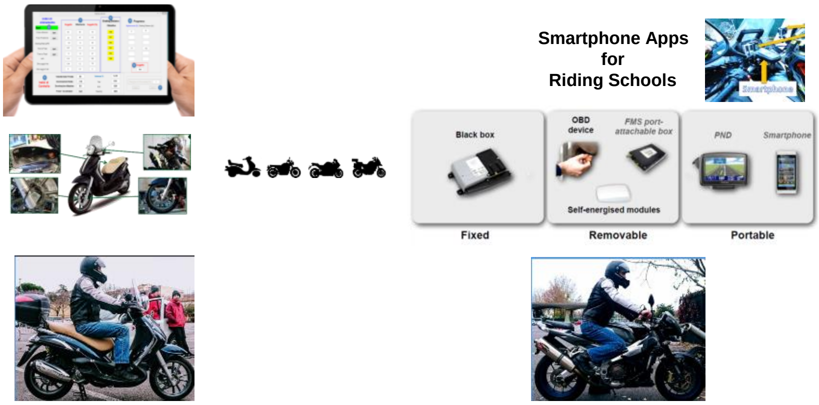


Figure 7-1. Low cost implementation with different motorcycles

7.5. Safety Implications of the research

This thesis provides knowledge and set a novel approach to understand the PTW rider behaviour performing braking as avoidance manoeuver. The research has shown the key parameters to characterize and predict the braking behaviour. The study provides a foundation for future training activities to increase rider competencies and for safety systems development. The thesis presents some directions for future research linked to safety including rider skills acquisition, naturalistic studies and applications for training that stem from the results

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ANNEX-1. Dichiarazione di consenso

Parte 2: Dichiarazione di consenso

Se sei d'accordo a partecipare allo studio, dovrai firmare il presente modulo di consenso.

Io sottoscritto, accetto in maniera volontaria di partecipare a questo studio. Sono consapevole che posso ritirarmi in qualsiasi momento, senza alcuna conseguenza. Dichiaro di aver avuto tempo sufficiente per prendere la mia decisione.

Sì	No	
☐	☐	Do il consenso all'uso di foto che mi ritraggono (con identità nascosta) per scopi didattici o per pubblicazioni.
☐	☐	Do il consenso all'uso di video che mi ritraggono (con identità nascosta dal casco) per scopi didattici o per pubblicazioni.

Mi sarà consegnata una copia firmata di questa informativa e modulo di consenso.

NOME E COGNOME DEL PARTECIPANTE (Stampatello):______________________________

FIRMA DEL PARTECIPANTE:________________________________

FIRMATO A _____________________, il ________________, 20_____.

Sì	No	
☐	☐	Al termine dello studio, desidero ricevere i risultati della mia prestazione sulla frenata d'emergenza.

N.B.: Potrebbero passare diversi mesi dal momento del test finale, prima che tali informazioni siano disponibili.

ESONERO DI RESPONSABILITA' DA QUALSIASI DANNO AL VEICOLO

Io sottoscritto__________________________________, con la presente sollevo i ricercatori, i proprietari del luogo in cui si svolge il test, l'Università Degli Studi di Firenze e chiunque dei suoi impiegati da qualsiasi responsabilità, per qualsiasi danno subito dal mio veicolo, dovuto alle manovre ed altre operazioni da me condotte sia durante il corso dell'esperimento, sia durante il viaggio da e per il luogo in cui si eseguono i test.

Firma _________________________, il _______________, 20_____.

ANNEX-2. Questionario sull'utilizzo della moto/scooter e sull'esperienza di guida

Nome del partecipante Clicca qui per inserire il testo.	CODICE del Partecipante	Data Clicca qui per scegliere la data.

1. **Profilo del guidatore**

   1.1. Sesso: **Maschio ☐** **Femmina ☐**

   1.2. Età: Clicca qui per inserire il numero. Anni

   1.3. Altezza: Inserire il numero. m. Peso: Inserire il numero. kg.

2. **Utilizzo della moto/scooter**

   2.1. Patente(i) di guida attualmente posseduta:

   A1 ☐ **A2 ☐** **A3 ☐** **B ☐** **Altro ☐**

   2.2. Tipo di patente di guida (trasmissione):

   CAMBIO MANUALE ☐ **AUTOMATICA ☐**

   2.3. Anno di prima acquisizione della patente: AAAA

   2.4. Motivi principali per cui utilizzi la moto/scooter: Scegliere una voce.

   2.5. Sei membro di qualche associazione/club di motociclisti?

   Sì ☐ **NO ☐**

Se al punto 2.1 hai dichiarato che non possiedi la patente B , procedi con la domanda 3.

Anno di acquisizione della patente auto: yyyy

2.5.1. Attualmente guidi un' auto? **SI'** ☐ **NO** ☐

2.5.2. Per quanti anni hai guidato un' auto? Clicca qui per inserire il numero. anni

3. Profilo del motociclo

3.1. Numero di moto attualmente possedute: Scegliere una voce.

Veicolo usato primariamente (se più di uno)

3.2. Tipo: Scegliere una voce.

3.3. Tipo di trasmissione: **CAMBIO MANUALE** ☐ **AUTOMATICA** ☐

3.4. ABS: **SI'** ☐ **NO** ☐

3.5. Marca e modello: Clicca qui per inserire il testo.

3.6. Anno: AAAA

3.7. Anno di acquisizione: AAAA

3.8. Cilindrata del motore: Inserire numero cc

3.9. Chilometraggio attuale (se il veicolo è usato, dichiarare solo il chilometraggio accumulato da te): Inserire numero km.

Moto secondaria - ***se non applicabile procedi al punto 4.***

3.10. Scopo principale: Scegliere una voce.

3.11. Tipo: Scegliere una voce.

3.12. Tipo di trasmissione: **CAMBIO MANUALE** ☐ **AUTOMATICA** ☐

3.13. ABS: **SI'** ☐ **NO** ☐

3.14. Marca e modello: Clicca qui per inserire il testo.

3.15. Anno: AAAA

3.16. Anno di acquisizione: AAAA

3.17. Potenza del motore: Inserire numero cc

3.18. Chilometraggio attuale (se il veicolo è usato, dichiarare solo il numero accumulato da te): Inserire numero km.

4. Motivazioni per usare la tua moto

Indica le tre principali motivazioni che ti spingono all'uso della moto, e indicando su scala da 1 a 3 "più importante"=1.

Ridurre i tempi di percorrenza (in confronto all'utilizzo dell'auto)	Clicca.
Per le sensazioni fisiche (accelerazione, guidare nelle curve, etc.)	Clicca.
Sviluppare la padronanza tecnica della guida	Clicca.
Per la sensazione di libertà	Clicca.
Per muoversi più facilmente nel traffico	Clicca.
Per trovare parcheggio più facilmente	Clicca.
Per risparmiare denaro negli spostamenti	Clicca.
Ridotte emissioni di CO^2 in confronto all'auto	Clicca.
Altre ragioni (specificare):	Clicca.

5. Abitudini del pilota

5.1. Frequenza con cui vai in moto (giorni al mese): Inserire numero

5.2. Media giornaliera di utilizzo della moto (minuti al giorno): Inserire numero

5.3. Quanti mesi all'anno usi la tua moto? Inserire numero

5.4. Numero di chilometri percorsi in un anno con la moto: Scegli un voce.km.

6. Corsi ed esperienze di tipo pratico

6.1. Lezioni di guida su moto o corsi frequentati (incluso i corsi per la patente di guida):

Nome del corso/scopo	Livello	Luogo di svolgimento	Data di svolgimento (mmm/aa)	Ore di pratica su moto
Clicca qui per inserire il testo.	Scegliere una voce.	Clicca qui per inserire il testo.	Scegli la data.	Inserire il numero.
Clicca qui per inserire il testo.	Scegliere una voce.	Clicca qui per inserire il testo.	Scegli la data.	Inserire il numero.
Clicca qui per inserire il testo.	Scegliere una voce.	Clicca qui per inserire il testo.	Scegli la data.	Inserire il numero.

6.2. Ha mai fatto qualche prova in pista? **SI' ☐** **NO ☐**

(*Si "no", procedi con la domanda 6.3)*

6.2.1. Quante ore con l'assistenza di un istruttore professionale? Inserire numero ore.

6.2.2. E/o, quante ore da solo? Inserire numero ore.

6.3. Ti sei mai esercitato ad effettuare frenate di emergenza (al limite)?

Sì ☐ **NO ☐**

(*Si "no", procedi con la domanda 6.4)*

6.3.1. Se sì, numero totale di sessioni: Inserire numero, durata di ogni sessione Inserire numero minuti.

6.3.2. Qual era il contesto?

☐ In un corso formativo

☐ Con l'assistenza di un video informativo

☐ Da solo

☐ Su una pista da gara

☐ Con l'aiuto degli amici

☐ Altro: Clicca qui per specificare.

6.4. Come giudichi il tuo modo di guidare in termini di sicurezza nel traffico? Scegli un opzione.

6.5. Come giudichi la tua abilità nell'individuare e rispondere velocemente ai rischi del traffico? Scegli un opzione.

6.6. Come giudichi la tua abilità nel frenare il più energeticamente e velocemente possibile? Scegli un opzione.

7. Riguardo la frenata d'emergenza, quale delle seguenti è la tua principale preoccupazione? (spunta un'opzione)

☐ Con quanta forza posso frenare?

☐ La ruota anteriore si bloccherà?

☐ Finirò oltre il manubrio?

☐ Come impedirò ai pneumatici di slittare?

☐ Altro: Inserire testo

8. Esperienza di situazioni di emergenza nel traffico

8.1. Quanti incidenti hai avuto da quando guidi la moto?

8.1.1. Numero di incidenti contro ostacoli: Inserire numero

8.1.2. Numero di incidenti con altri utenti della strada (incluso pedoni): Inserire numero

8.2. In almeno uno dei questi incidenti, sei stato tu ad entrare in collisione urtando l'altro? In altre parole, escludi gli incidenti in cui altri hanno investito. **Sì** ☐ **NO** ☐

(Si "no", procedi con la domanda 8.4)

8.2.1. Che tipo di utente della strada era? Scegli un opzione.

8.2.2. Mese/anno dell'incidente: Scegli la data.

8.2.3. Come è avvenuto?

☐ Il veicolo proveniente dalla direzione opposta ha girato di fronte a me ad un incrocio

☐ Collisione con un veicolo che viaggiava nella stessa direzione (es. cambio di corsia)

☐ Ho tamponato il veicolo che mi precedeva

☐ Collisione con un veicolo proveniente da una via/strada laterale

☐ Altro: Clicca qui per inserire il testo.

8.3. Ulteriori collisioni con altri utenti della strada:

8.3.1. Che tipo di utente della strada era? Scegli un opzione.

8.3.2. Mese/anno dell'incidente: Scegli la data.

8.3.3. Come è avvenuto?

☐ Il veicolo proveniente dalla direzione opposta ha girato di fronte a me ad un incrocio

☐ Collisione con un veicolo che viaggiava nella stessa direzione (es. cambio di corsia)

☐ Ho tamponato il veicolo che mi precedeva

☐ Collisione con un veicolo proveniente da una via/strada laterale

☐ Altro: Clicca qui per inserire il testo.

8.4. Durante la guida, quanto spesso hai rischiato un incidente con un altro veicolo o un altro utente della strada (es. ciclista, pedone)? Scegli un opzione.

9. La tua patente prevede l'obbligo di indossare occhiali da vista?

Sì ☐ NO ☐

10. Attrezzatura protettiva personale.

Controlla se hai la seguente attrezzatura. Per le voci non spuntate, indica la tua taglia, dal momento che abbiamo la possibilità di fornire l'attrezzatura ai partecipanti.

Ho	***Oggetto***	***Taglia***
☐	Casco	Inserire testo
☐	Giacca da moto (con protezioni interne)	Inserire testo
☐	Pantaloni da moto (con protezioni interne)	Inserire testo
☐	Guanti da moto	Inserire testo
☐	Stivali che coprono le caviglie	Inserire testo

ANNEX-3. Questionario per gli istruttori di guida moto

1. Profilo dell'istruttore

1.1. Ti sei sottoposto ad un programma di accreditamento/certificazione, da parte di un ente terzo? ____

1.2. Da quanti anni insegni ad andare in moto?

Meno di 1___ da 1 a 3___ da 3 a 5___ da 5 a 10___ più di 10___

1.3. Con che frequenza insegni (teoria + pratica)? _______ giorni a settimana, ________ore al giorno.

1.4. Quante ore a settimana di pratica? ______
Quante ore a settimana di teoria? ______

1.5. Quanti allievi ci sono per ogni istruttore durante le lezioni di pratica? ________

2. Utilizzo della moto/scooter

2.1. Patente(i) di guida attualmente posseduta(e): A1 A2 A3 B Altro: ______

2.2. Tipo di patente di guida (trasmissione): ___ CAMBIO MANUALE ___AUTOMATICA

2.3. Anno di conseguimento della patente A ____________

2.4. Usi la moto per i tuoi spostamenti quotidiani? SI__ NO ___

2.4.1. Se SI, quale genere di moto? (cerchiare una sola risposta)

SCOOTER	SPORT	CRUISER (Esempio: Harley Davidson)
TURISTICA	CROSS	ENDURO (Esempio: BMW GS1200)
STRADALE	STANDARD	Altro: _______________

2.5. Tipo di trasmissione: ___ CAMBIO MANUALE ___AUTOMATICA

2.6. ABS: SI___ NO ___

Se “SI”, perché usi l’ABS? ____

2.7. Marca e modello ____

2.8. Anno ____________

2.9. Cilindrata del motore _________ cc

2.10. Motivazione principale per cui utilizzi la moto:

- ☐ Muoversi in città (ad es. recarsi a lavoro, fare commissioni)
- ☐ Per lavoro (specificare): ____________________
- ☐ Piacere/tempo libero
- ☐ Sport
- ☐ Viaggio
- ☐ Altro : ____

3. Insegnamento e apprendimento della frenata di emergenza

3.1. Insegni ad eseguire frenate al limite? SI NO

Se “sì”, in quale corso? ___________________________

3.2. Basandoti sulla tua esperienza, l’esame di guida per ciò che riguarda la frenata di emergenza riflette il livello di abilità che il motociclista dovrebbe avere nella guida di tutti i giorni? SI NO

3.3. Quando insegni ad eseguire la frenata di emergenza, mostri la manovra agli studenti?

SI NO

3.4. Descrivi come spiega la prima volta agli allievi come debbano eseguire la frenata d’emergenza (fasi/punti chiave):

____

____

3.5. Su cosa ti basi per valutare un'esecuzione pratica? (Spuntare le DUE principali caratteristiche)

- ☐ Spazio di arresto
- ☐ Coordinazione e controllo dei movimenti del corpo
- ☐ Assenza di slittamento
- ☐ Uniformità di decelerazione
- ☐ Arresto in un punto specifico
- ☐ Uso dei comandi del freno e/o acceleratore
- ☐ Stabilità della moto a completamento della frenata
- ☐ Uso del freno bilanciato tra anteriore e posteriore
- ☐ Altro: ________________________

Eventuali commenti aggiuntivi:

____

3.6. Indica uno o due aspetti-competenze di questa lista che risultano più difficili per la maggioranza degli allievi:

- ☐ Riduzioni dello spazio di arresto
- ☐ Coordinazione e controllo dei movimenti del corpo
- ☐ Assenza di slittamento
- ☐ Uniformità di decelerazione
- ☐ Arresto in un punto specifico
- ☐ Uso dei comandi del freno e/o acceleratore
- ☐ Stabilità della moto a completamento della frenata
- ☐ Uso del freno bilanciato tra anteriore e posteriore
- ☐ Altro: ________________________

3.7. Quale dei seguenti tipi di feedback fornisci agli studenti che fanno pratica sulla frenata di emergenza? (Spunti quelli applicabili, max 4 casi)

11. Comunico agli studenti quando hanno raggiunto l'obiettivo
12. Descrivo gli errori
13. Dimostro cosa hanno fatto in maniera non corretta
14. Descrivo quale potrebbe essere la conseguenza dell'errore

15. Descrivo perché hanno fatto quell'errore
16. Descrivo come correggere l'errore
17. Dimostro come correggere l'errore
18. Altro:______________

3.8. I tuoi alleivi si esercitano sulla frenata nello stesso modo in cui poi la eseguiranno durante l'esame di guida? SI NO

3.9. Chiedi agli studenti di esercitarsi nella frenata di emergenza in modi diversi? Descrivi ciascun caso:

____

____

____

____

____

3.10. Quali gruppi di studenti tendono ad apprendere la frenata d'emergenza più facilmente/ velocemente? (cerchiarne una)

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46-55 56-65

3.11. Quali sono i più grossi ostacoli che riscontri quando aiuti gli studenti a imparare la frenata d'emergenza?

____

____

____

4. Questioni di sicurezza inerenti la pratica della frenata d'emergenza

4.1. Basandoti sulla tua esperienza di isruttore, qual è il fattore maggiormente critico nell'assicurare la sicurezza durante le esercitazioni sulla frenata di emergenza?

____

4.2. Quali informazioni dai agli studenti a proposito dei pericoli legati alle esercitazioni sulla frenata d'emergenza?

____

____

____

4.3. Quale velocità prescrivi agli studenti di raggiungere prima di iniziare la frenata d'emergenza?

____ km/h

4.4. Qual è la velocità massima che si può raggiungere per praticare la frenata di emergenza, affinché sia garantito il miglior equilibrio possibile tra velocità elevata e rischio di incidente? ________ km/h

5. Tecnologia di supporto per l'insegnamento e l'apprendimento

5.1. *Formazione relativa alla frenata d'emergenza*. Quale dei seguenti tipi di informazioni fornite come feedback sulle prove sarebbe più utile per aiutare gli studenti a migliorare la propria abilità nella frenata d'emergenza? Ordina da 1 a 6 (1 il più importante).

- ☐ Spazio di arresto
- ☐ Efficacia della frenata (es. Troppo energica, troppo debole nel complesso)
- ☐ Rapporto tra la pressione di frenata anterior vs. posteriore
- ☐ Rapidità di risposta ai rischi del traffico
- ☐ Visualizzazione dei video dei tentativi pratici
- ☐ Altro (specificare): ____

5.2. *Formazione relativa alla frenata d'emergenza*. Quale dei seguenti tipi di tecnologia ritieni utile per ottenere metodi di insegnamento più efficaci nella frenata d'emergenza?

- ☐ Simulatore di guida per migliorare le capacità di controllo
- ☐ Simulatore di guida in ambiente virtuale per insegnare le regole del traffico
- ☐ Simulatore di guida in ambiente virtuale per istruire sulla percezione del pericolo
- ☐ Multimedia (es. online, apps) per allenarsi sulla percezione del pericolo
- ☐ Moto strumentata (per registrare la decelerazione, l'uso dei freni, spazio di frenata)
- ☐ Altro (specificare): ____
- ☐ Nessuna delle precedenti (spiegare):____ ____

5.3. *Metodi e ausili alla formazione*: Attualmente usa qualche tipo di tecnologia o attrezzatura come supporto all' istruzione? (es. video camera, simulatore) SI NO

Se "Sì", per favore specificare: ____