In-depth Crash Causation Analysis of Motorcyclist Crashes

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Abstract: Motorcyclists as vulnerable road users are likely to be seriously injured during crashes. Realizing the need for mitigating the serious consequences of motorcyclist crashes, this paper aims to investigate and identify the factors contributing to the crash occurrence. The in-depth data used for the purpose of this study allows the detailed analysis of contributory factors and the whole human functional failure chain leading to the crash as well as the crash mechanism. Not only the failure of motorcyclists leading to the crash was analysed, but also the failure of passenger vehicle drivers involved in a collision with a motorcyclist. To define the risk factors of motorcycle-vehicle crashes, the obtained results focused on the motorcycle-vehicle crashes were compared with the two passenger vehicle crashes. The most typical vehicle–motorcycle crash caused by vehicle driver failure is right of way violation. While motorcyclists frequently fail at the diagnosis level (especially incorrect evaluation of a road difficulty), vehicle drivers mostly fail at the detection level, especially in the intersections. Obtained data highlighted the necessity of the educational and preventive activities focused differently on the motorcyclist and vehicle drivers.

1 INTRODUCTION

Motorcyclists are with pedestrians and cyclists among the most vulnerable road users. Motorcyclists are around 16-20 times more likely involved in an injury or fatal crash in comparison with passenger vehicle drivers (Walton, 2012) and 25times more likely to be fatally injured per million vehicle kilometres than passenger vehicle drivers (ONISR, 2010). The higher injury risk is mainly caused by low motorcyclist protection (compared to the vehicle crew) and higher speeds in comparison with the other vulnerable road users. (Obenski et al., 2011)

2 LITERATURE REVIEW

The most common causes of motorcycle crashes are failure to give way, rider losing control (especially in the curve) and overtaking (Clarke et al., 2004). Even though the failure to give way belongs to the most common causes of motorcycle crashes, only approximately 20% of crashes are non-priority crashes caused by motorcycle failures (Clarke et al., 2004; Clabaux et al., 2012; Pai, 2011). Motorcycle non-priority crashes belong to the riskiest situations for the motorcyclist, the crashes are often characterised by serious consequences. (Clabaux et al., 2012; Pai, 2011). These crash scenarios predominantly involve a driver failing to detect the presence of an oncoming motorcycle or failure in the decision-making process (Clarke et al. 2004; MAIDS, 2004; Pai, 2011; Crundall, 2008).

The safe task performance depends on sensory detection of all the relevant data (van Elslande). The detection failures could occur if the driver overlooked a motorcyclist approaching the intersection. For these types of crashes is common that the other users declare that he had looked in the motorcycle driving direction prior to undertaking manoeuvre but did not see the motorcyclist – the crashes are referred to as "looked-but-failed-to-see" (Clabaux et al., 2012, Brown, 2002, Clarke, 2007). The crashes could be explained by a phenomenon called inattention blindness (Pammer & Blink, 2013; Pammer et al., 2017; Clark et al., 2004). Inattentional blindness crashes are usually caused by factors such as low

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conspicuity, divided attention and high expectation or lower arousal (Green, 2004; Clark et al., 2004). The conspicuity could be divided into two categories – sensory which refers to physical properties of information and cognitive which refers to the perceived relevance of information (Grissinger, 2012). Conspicuity as one of the key factors in motorcycle road crashes is often associated with motorcycle size, low contrast with the road and its surroundings, speed etc. (Khalid, 2021; Clabaux et al., 2012; de Craen, Doumen, & van Norden, 2014; Mitsopoulos- Rubens & Lenne, 2012). The "looked-but-failed-to-see" mostly occurred in the good visibility condition without other contributing risk factors such as inexperience, intoxication or fatigue (Pai, 2011). The majority of the right of way motorcycle crashes occur at the T-intersections. (Clark et al, 2004).

Following a sequential logic of driver malfunctions, once the detection stage is correctly performed is necessary to process acquired information. The functional stage resulting from the detection and processing of the event encountered consists in the decision-making processes (van Elslande, 2008). The incorrect decision could be influenced by a wrong assessment of the motorcycle speed and/or distance. The misperception of a motorcycle's motion is related to the overestimation of the arrival time of small objects - the "size-arrival effect" (DeLucia, 1991, Caird and Hancock, 1994; Horswill, 2005).

As evidenced from the literature review, the motorcyclist belongs to the most seriously injured crash participants and is necessary to focus on the causes of their crashes, especially motorcycle–vehicle intersection crashes. The aim of this study is to analyze the failures leading to these crashes - whether from the point of view of motorcyclists' failures or other participants. The study aims to use in-depth crash data which allows the detailed analysis of contributory factors. In comparison to the studies which used official police data, in-depth data allows analyzing not only the whole human functional failure chain but also the crash mechanism (including the possibility of reaction or driving speed before the crash).

3 METHODS/

3.1 Czech In-depth Study

For the purpose of this study, data from the Czech In-depth Accident Study has been used. The project focuses on-road accidents with injuries that occurred within a defined region of South Moravia. The database currently includes more than 2000 crashes, 376 from this dataset involved motorcyclists. The in-depth crash investigation is focused on the failure of the whole system road user – infrastructure – vehicle. The investigation includes an individual interview with crash participants focused on all relevant information related to the crash causes and consequences.

3.2 Human Failure

The analysis will use the van Elslande human functional failure model (van Elslande, 2008) which assumes a sequential information processing chain of human functions involved in information gathering, processing, decision and action. During crash analysis, the functional buckle is stopped in the stage of rupture in the progress of the driver which leads to losing control of the situation. At a general stage, the classification model allows distinguishing Failures at the information detection stage, Failures at the diagnostic stage, Failures at the prognostic stage, Failures at the decision stage on the execution of a specific manoeuvre, Failures at the psychomotor stage of taking action, and Overall failures dealing with the psycho-physiological capacities of the driver.

In each crash configuration, even the most often contributing factors will be analyzed. Similar factors affecting the likelihood of traffic accident causation as by Petridou et al. (2000) was used. The human factors contributing to crashes are modulate risk-taking factors such as speeding or non-adjustment of driving, conscious violation of traffic rules, risky overtaking, the influence of alcohol or other psychoactive substances and reduce capability to meet traffic contingencies such as inexperience, reduction of cognitive and psychomotoric function in relation to higher age, panic reaction, glare, health indisposition, drowsiness/fatigue or microsleep, incorrect evaluation of the situation, limited view, inattention, mental or somatic handicap.

4 RESULTS

The motorcycle crashes were subdivided according to the crash type – individual motorcycle crashes on the straight road and in a curve; vehicle-motorcycle crashes on the straight road and in a curve; intersection crashes. The human functional failure was analyzed in relation to the road user.

The most common types of motorcycle accidents are motorcycle-vehicle crashes at the intersection (36.4%), followed by motorcycle-vehicle crashes on the straight road (21.3%) and individual motorcycle crashes in a curve (12.3%).

4.1 Single Motorcycle Crashes

From the whole motorcycle crashes dataset, 29,3 % involve single motorcycle crashes. The motorcycle crashes were subdivided into two categories based on the crash location - crashes in the curve (12,3 % of the total crashes), crashes on the straight road (11,7 % of the total crashes). Crashes in the curve mainly involve loss of control of the motorcycle due to excessive speed. The most common type of failure which leads to curve crashes is the failure on the diagnosis level, specifically incorrect evaluation of road conditions. In comparison to the curve crashes, diagnosis level failure is less common on a straight road segment. The other common failure of the motorcycle driver on diagnostic level is incorrect evaluation of a gap. Crashes in the curve and on a straight segment show equal contributing factors - speeding or non-adjustment of driving, incorrect evaluation of the situation and inexperience.

Table 1: Motorcyclist failures in the single motorcycle crashes in the curve.

Diagnosis failure (73,7 %)	Incorrect evaluation of a road difficulty (71,1 %)	speeding or non-adjustment of driving (47,9 %) incorrect evaluation of the situation (14,1 %) inexperience (12,7 %)
Prognosis failure (13,2 %)	Expecting no perturbation ahead (10,5 %)	

Table 2: Motorcyclist failures in the single motorcycle crashes on the straight road.

Diagnosis failure (41,2 %)	Incorrect evaluation of a road difficulty (23,5 %) Incorrect evaluation of a gap (17,6 %)	speeding or non-adjustment of driving (39,6 %) inattention (14,6 %) Inexperience (10,4 %) incorrect evaluation of the situation (10,4 %)
Overall failure (20,6 %)	Overstretching cognitive capacities (11,8 %)	

4.2 Motorcycle – Vehicle Crashes

Motorcycle-vehicle crashes are the most common crash type (71 %). For detailed analysis were separately analyzed motorcycle and passenger vehicle failure.

4.2.1 Non-Intersection Crashes

Non-intersection crashes are more often caused by motorcycle failure. The comparison of the motorcycle-vehicle crashes on the straight road sections and in the curve shows a similar representation of the most common failure types and contributing factors of individual crash participants. While motorcyclists most often fail at the diagnosis level (in terms of a collision with another vehicle similarly as in terms of single-vehicle collisions), the failure of vehicle drivers leading to a collision with a motorcyclist is most often at the perception/detection level.

Table 3: Driver failures in the motorcycle – vehicle crashes on the straight road.

Motorcyclist failure		
Diagnosis failure (35,5 %)	Incorrect evaluation of a gap (22,6 %)	Inattention (39,6 %) speeding or non-adjustment of driving (18,9 %)
Prognosis failure (22,9 %)	Expecting no perturbation ahead (12,9 %) Expecting another user not to perform a manoeuvre (9,7 %)	
Vehicle driver failure		
Detection failure (70,8 %)	Information acquisition focused on a partial component of the situation (34,8 %) Cursory or hurried information acquisition (26,1 %)	Inattention (44,4 %) incorrect evaluation of the situation (18,5 %)
Diagnosis failure (16,7 %)	Incorrect evaluation of a gap (8,7 %)	

The frequency of detection level failure decreases in the curves in comparison to the straight segments. The most common failures at the detection level are information acquisition focused on a partial component of the situation and cursory or hurried information acquisition. The most common contributory factors of vehicle drivers in the curve and on a straight segment are inattention and incorrect evaluation of the situation.

Table 4: Driver failures in the motorcycle – vehicle crashes in the curve.

Motorcyclist failure		
Diagnosis failure (58,8 %)	Incorrect evaluation of a road difficulty (58,8 %)	speeding or non-adjustment of driving (39,5 %) Inattention (13,2 %)
Prognosis failure (23,5 %)	Expecting no perturbation ahead (17,6 %)	
Vehicle driver failure		
Detection failure (57,6 %)	Cursory or hurried information acquisition (25 %) Information acquisition focused on a partial component of the situation (25 %)	Inattention (42,9 %) incorrect evaluation of the situation (18,6 %)
Diagnosis failure (18,2 %)	Incorrect evaluation of a road difficulty (9,4 %)	

4.2.2 Motorcycle – Vehicle Intersection Crashes

While non-intersection crashes are more often caused by motorcycle failure, with intersection crashes the situation is reversed. At intersections, motorcycle-vehicle crashes are most often caused by a vehicle driver failure. The vehicle driver failure is most commonly on the detection level. The crashes are commonly not only due to the information acquisition focused on a partial component of the situation and cursory or hurried information acquisition as in non-intersection crashes but also due to the non-detection in visibility constraints conditions.

Most of the intersection crashes are caused by right of way (ROW) violations. For purpose of detailed analyses of the right of way crashes were described individual types of right of way violations. The most common failure of vehicle drivers when making a left turn is not giving a right of way to the oncoming motorcycle.

Only about 20 % of all intersection crashes are caused by motorcycle failure and motorcyclists mostly fail at the diagnosis level (similarly to non-intersection crashes and individual crashes). Most of contributing factors, besides risky overtaking, are also similar to the non-intersection motorcycle–vehicle crashes and individual motorcycle crashes. Vehicle drivers mostly fail to see oncoming motorcycle or motorcycle coming from his/her left side.

Table 5: Driver failures in the motorcycle – vehicle intersection crashes.

Motorcycle failure		
Diagnosis failure (44,4 %)	Incorrect evaluation of a road difficulty (22,2 %) Incorrect evaluation of a gap (11,1 %)	Inattention (34,1 %) incorrect evaluation of the situation (22 %) Risky overtaking (14,6 %)
Detection failure (22,2 %)	Non-detection in visibility constraints condition (11,1%)	
Vehicle driver failure		
Detection failure (80,2 %)	Information acquisition focused on a partial component of the situation (38 %) Non-detection in visibility constraints conditions (26,6 %) Cursory or hurried information acquisition (13,9 %)	Inattention (50,4 %) incorrect evaluation of the situation (14,5 %) Limited view (13 %)
Diagnosis failure (6,2 %)	Incorrect evaluation of a road difficulty (2,5 %) Incorrect evaluation of a gap (2,5 %)	

4.3 Two Passenger Vehicle Crashes

4.3.1 Two Passenger Vehicle Intersection Crashes

For the comparison and definition of the factors which affect the failure in the motorcycle perception by vehicle drivers, also the two-vehicle intersection crashes were analyzed with the focus on the human functional failure and contributory factors. The obtained results show a reduction in the detection failure in comparison with failure in the perception of the approaching motorcycle (an increase of about 11 %). The more frequently drivers in the two-vehicle intersection crashes failed in the prognosis stage.

Table 6: Driver failures in the two passenger vehicle intersection crashes.

Vehicle driver failure		
Detection failure (69,7 %)	Information acquisition focused on a partial component of the situation (43,2 %) Cursory or hurried information acquisition (10,2 %) Non-detection in visibility constraints conditions (5,7 %) Momentary interruption in information acquisition activity (5,7 %)	Inattention (42,5 %) incorrect evaluation of the situation (18,1 %) Limited view (7,9 %) Involutional changes (7,1 %)
Diagnosis failure (13,5 %)	Mistaken understanding of how a site functions (4,5 %) Erroneous evaluation of a passing road difficulty (3,5 %)	
Prognosis failure (11,2 %)	Expecting another user not to perform a manoeuvre (6,8 %) Actively expecting another user to take regulating action (2,3 %)	Inattention (42,9 %) incorrect evaluation of the situation (18,6 %)

4.4 Comparison of Two-Vehicle Crashes at the Intersection

The vehicle - motorcycle intersection crashes are caused mainly by vehicle driver failure. For the definition of risk factors associated with these types of crashes, also some of the factors influencing the mechanism of the motorcycle – vehicle and two passenger vehicle crashes were compared.

The majority of vehicle-motorcycle crashes occur at the T-intersection (two-vehicle crashes at T-intersection are less common in comparison with motorcycle-vehicle crashes). Vehicle drivers react almost about 25% less frequently to the approaching motorcycle in comparison with the reaction to the vehicle approaching the intersection.

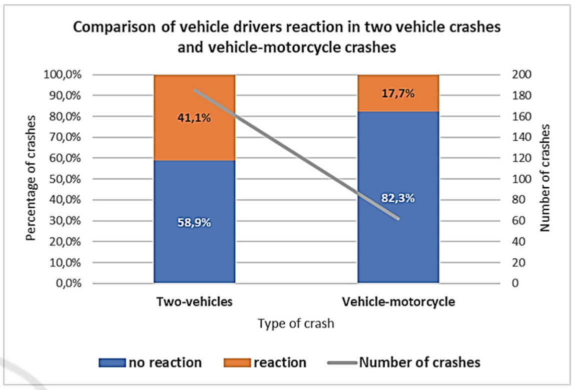

Figure 1: Comparison of vehicle driver's reaction in two vehicle crashes and vehicle-motorcycle crashes.

For more detailed analyses of pre-collision scenarios, were compared the pre-collision speed and collision speed for both two-vehicle crashes and vehicle-motorcycle crashes. Before the collision, more than 50 % of vehicle drivers, who failed to see motorcycles, drove slower than 21 kph. On the other side, drivers who failed to see another vehicle drove faster than 30 kph about 10 % more frequently than vehicle drivers, who failed to see motorcycles. For collision speed is this difference even greater. The collision speed of vehicle drivers, who fail to see an approaching vehicle, was above 30 kph two times more common than the collision speed of vehicle drivers, who fail to see the approaching motorcycles.

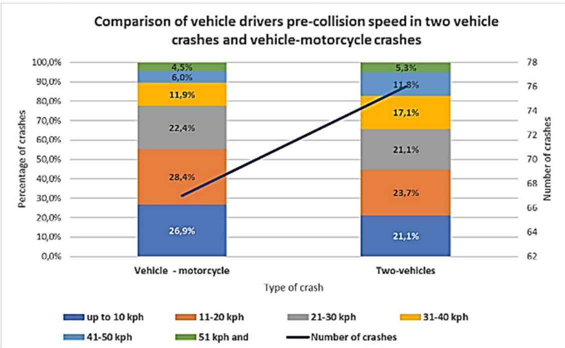

Figure 2: Comparison of vehicle driver's (who failed to give way) pre-collision speed in two vehicle crashes and vehicle-motorcycle crashes.

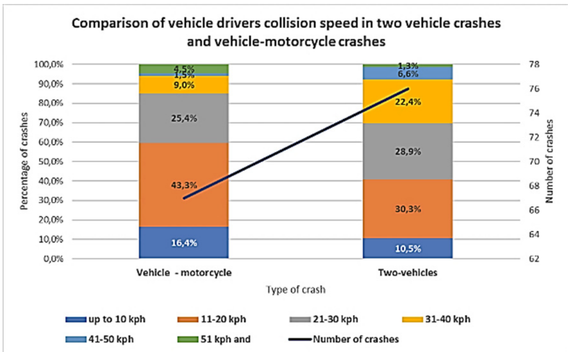

Figure 3: Comparison of vehicle driver's (who failed to give way) pre-collision speed in two vehicle crashes and vehicle-motorcycle crashes.

5 CONCLUSIONS

Motorcyclist belongs to the most seriously injured crash participants. The study was carried out to determine the common causes of motorcycle crashes and analyse the failures leading to these crashes - whether from the point of view of motorcyclists' failures or other participants. Around half of the total cases (single motorcycle and vehicle-motorcycle collisions) are caused by motorcyclist failure, so the provided data confirmed that initiatives in motorcycle safety and countermeasures should be targeted on both – motorcyclists and vehicle drivers, but human failure causation differs, similarly, crash mechanisms differ. The study uses in-depth crash data which allows the detailed analysis of contributory and also allows to analyse the whole human functional failure chain and the crash mechanism (including the possibility of reaction or driving speed before the crash). This is a significant benefit compared to the use of national crash data. Analyses of the in-depth data allows to describe the vehicle driver's/motorcyclist's behaviour before the crash and the most common factors that contribute to failure of vehicle driver/motorcyclist. This study specifically focused on vehicle-motorcycle crashes at the intersections, which belongs to the most common motorcycle crashes. These crashes are more likely to be the fault of vehicle drivers, who fail to see motorcycles. Several different theories were brought to explain, why vehicle drivers fail to see motorcycles despite, being in full view (Pammer et al., 2017; Green, 2004; Crundall, 2012; Clabaux et al., 2012). The specificity of the study is the comparison of the factors influencing the mechanism of the motorcycle–vehicle and two passenger vehicle crashes.

Similarly as described in RoSPA (2016), also results from this study shows that crashes on curves are often caused by motorcyclist failure especially non-adjustment of speed or misjudgement of the curve properties. Contributory factors of the motorcycle failures are not only non-adjustment of speed and incorrect situation evaluation but also inexperience. Di Stasi et al. (2011) found in their study that failure to adapt to external conditions is often due to the inexperience of motorcyclists and the associated lack of awareness of the impending danger. This type of crash are nearly three times as likely (compared with all the cases) to be rated as an 'inexperienced' motorcyclist (RoSPA, 2016). Clark (2007) suggest that inexperienced motorcyclists are more likely to participate in curve crashes. On the other side, experienced vehicle drivers are more susceptible to ROW crashes.

Crashes on the straight road have some similar characteristics to crashes on curves – the crashes are mostly caused by motorcycle's failure on diagnosis level and the most common contributing factors are speeding or non-adjustment of driving and inattention. The crashes caused by motorcyclists' failure are largely related to insufficient safety distance and loss of control over the motorcycle. Insufficient safety distance is more likely motorcyclist failure than the other road user. (RoSPA, 2016)

The obtained results can thus help to focus on the risk aspects of these crashes and their mitigation. While motorcyclists frequently fail at the diagnosis level (especially incorrect evaluation of a road difficulty), vehicle drivers mostly fail at the detection level, especially in the intersections. Similarly as described e.g. by Clabaux et al. (2012) or Clark (2004), also in this study was confirmed that the majority of motorcycle-vehicle crashes at the intersection are caused by vehicle drivers' failure.
About 80 % of vehicle drivers failed on detection level. The obtained results confirmed Hurt et al. (1981) conclusions, that in post-crash interviews vehicle drivers involved in such crashes normally stated that they did not see motorcycles when making manoeuvres until the last moment before collisions. Pammer (2017) suggested, that one of the key factors of crashes are divided attention expectation or attention set. This hypothesis suggests that vehicle drivers don't expect to see motorcycles in the driving environment because they are rare on the road compared to other road users. Therefore, we compared crashes of vehicle drivers, who failed to see approaching motorcycles and crashes of vehicle drivers, who failed to see an approaching vehicle. In

vehicle-motorcycle crashes, vehicle drivers are more likely to fail at detection level in comparison to two-vehicle crashes. These vehicle drivers commonly (26,6 %) fail in detecting motorcycles in visibility constraints conditions. This is not common for vehicle drivers in two-vehicle crashes. Vehicle drivers in two-vehicle intersection crashes more frequently failed in the prognosis level – vehicle driver incorrectly evaluate potential scenarios that may occur in a given situation.

Similarly as described by Clark et al. (2004), the majority of right of way crashes with motorcycles were investigated at the T-intersection. Another difference between vehicle-motorcycle crashes and two-vehicle crashes in intersections is that vehicle drivers (who should give way) drive faster before a collision. They drive above 30 kph about 10 % more frequently than vehicle drivers, who fail to see the approaching motorcycle. Speed could be the factor influencing the ability to correctly perceive the situation in traffic. The collision speed of vehicle drivers, who fail to see approaching vehicles, was above 30 kph even two times more common than the collision speed of vehicle drivers, who fail to see the approaching motorcycle.

In this study, was not distinguished controlled and uncontrolled (intersection with no traffic light, only with road markings or signs) intersection, because this was not necessary for purpose of the analyse. Also, (similarly to the finding of Hole et. al, 1996) there were only a few cases of ROW crashes, that occur at a controlled intersection. This study did not consider the level of experience of both motorcyclists and vehicle drivers. Also, the factors which could influence conspicuity such as the clothing colour, helmet colour or use of any reflective elements were not analyzed.

Drivers need to be aware of the number of factors influencing motorcycle detection. The motorcyclist conspicuity and detectability could be positively affected by different conspicuity aids such as lights, reflective vests, and coloured helmets. (e.g. Al-Awar Smithe, 2010; Mitsopoulos-Rubens, 2012; Helman, 2012; de Craen, 2014; Wells 2004). The educational activities should improve also motorcycle drivers' skills and driving techniques especially in potentially risky situations (especially inexperienced drivers), the sensation-seeking and tendency to risky driving should be also targeted. Road design strategies such as traffic calming or enforcement strategies could indirectly improve motorcyclists' perceptibility, at least in urban environments.

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