Impact

The Journal of the Institute of Traffic Accident Investigators

Summer 2021 Volume 29 No. 1

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From the Editor

Firstly I would like to take this opportunity to thank Tony Foster for dusting off his Editor's hat and coming out of retirement to assist with the last edition of Impact. Tony's help has been very much appreciated.

I have recently been in discussions with Victor Craig of the National Association of Professional Accident Reconstruction Specialists (NAPARS), and the Editor of the associations Accident Reconstruction Journal. We have each expressed interest in articles published by the other, and the two bodies have agreed a share of material to try and bridge the occasional divide that there is between the UK and the USA.

This edition features an article by Dr Gemma Briggs of The Open University, who is a Senior Lecturer in Psychology. Her work centres around distracted driving, and the effects of phone use, including hands-free, on driving ability. She is keen to work with the institute and its members - particularly Police Collision Investigators - to further her work in this area. Equally she is more than happy to offer advice to investigators in this regard. Consequently, Gemma is presenting a series of webinars, starting on 15th September, in which she will be discussing her work (see advert on page 5).

Stephen Cash

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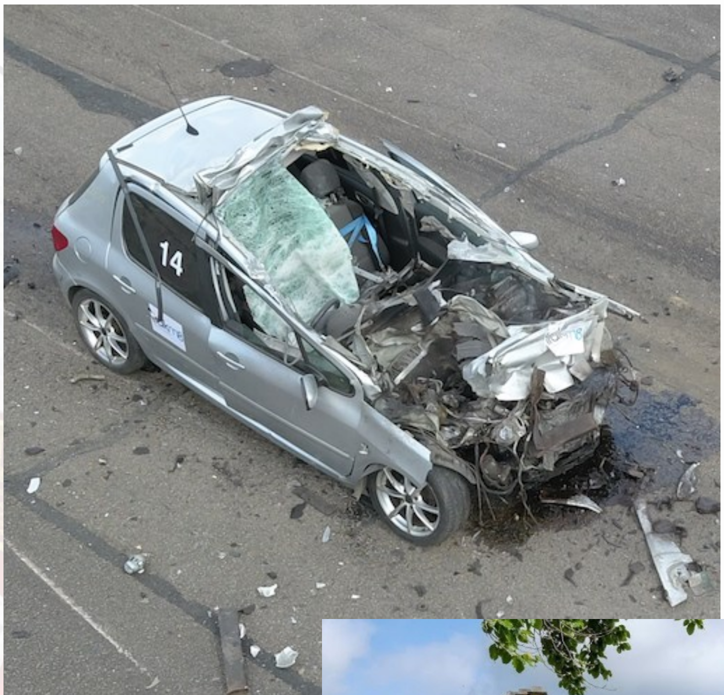

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The Institute of Traffic Accident Investigators provides a means of communication, education, representation and regulation in the field of traffic accident investigation. Its main aim is to provide a forum for spreading knowledge and enhancing experience amongst those engaged in the discipline.

Further, the Institute seeks to promote a professional approach to traffic accident investigation and, through its rules and discipline procedures, to encourage honesty and integrity.

The current membership represents a wide spectrum of professions, including police officers, researchers, lecturers in higher education, and private practitioners.

Membership of the Institute will be of assistance to anyone wishing to be informed of current developments and thinking in the discipline of traffic accident investigation, in addition to those in a career where the use and understanding of the principles of accident investigation are required.

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Letters to the Editor are welcomed. Opinions expressed in letters and articles within *'Impact'* do not necessarily reflect those of the Editorial Board or the Institute.

Webinar

"What do we know about distracted driving?: motivations, behaviours and consequences"

Wednesday 15th September 2021

The Institute will be presenting the first in a series of a one-hour webinars for the membership on Wednesday 15th September 2021 in which applied cognitive psychologist, Dr Gemma Briggs – a senior lecturer at The Open University – will discuss research findings on driver distraction.

Gemma has researched this area for many years, and her collaborative research has provided new explanations for both how and why phone use leads to deteriorated driving.

This session will explain how distraction can have measurable effects on certain aspects of driving, many of which will be familiar to collision investigators. This knowledge can be used to help explain driver testimony after a collision, as well as understanding certain driving behaviours prior to a collision.

The session will also discuss the cognitive nature of distraction, demonstrating that having both hands on the wheel and both eyes on the road does not constitute 'safe' driving, if the driver is also engaged in a mobile phone conversation.

Gemma will be very happy to answer questions relating to driver distraction in the session and will be providing further sessions in the future too.

Members wishing to register to take part in the webinar will find further details on the Institute website at www.itai.org

Visit the Institute's website at www.itai.org

'Impact' subscription, and all other enquiries should be addressed to

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Braking Capabilities of Motorcyclists - An Update

Nathan Rose

Principal Accident Reconstructionist - Luminous Forensics

Introduction

This article reviews published studies related to the deceleration that motorcyclists can produce by braking. Several concepts are important to consider while interpreting these studies. First, there is a difference between the braking capabilities of a motorcycle and the deceleration an average rider can achieve on that motorcycle. Most riders will not be capable of fully utilizing the braking capabilities of their motorcycle. Second, it is important to note that many of these studies were conducted with riders who were not confronted with actual emergency situations. Instead, they were conducted on test tracks, roads without hazards, or parking lots. This means that these studies capture what riders are capable of under ideal circumstances. When confronted with actual emergencies, many riders may not achieve the decelerations that riders in these studies did.

An important point is made by Ayres and *Kubose* [1], who noted that *"it has long been understood that faster responses tend to be less accurate…there is no single value that can be said to represent the reaction time of even one person for one task, without considering the accuracy of task performance."* This is relevant to the braking deceleration achieved by motorcyclists because "*a driver would tend to respond quickly although perhaps not very accurately when a collision is imminent, but would take a more careful approach (accurate, appropriate) with more time available."* Thus, *"one should not expect…that drivers will efficiently use all time available to make an optimum avoidance maneuver…it is unreasonable to expect optimal response timing and maneuver performance by drivers faced with emergencies."*

It is also important to state that riding experience does not necessarily equate to the ability to achieve higher decelerations during emergency braking. When we speak of riding experience, it is important to ask: experienced at what? Even riders who have ridden many miles are not frequently confronted with the need to brake in an emergency fashion, and so, even experience riders may not be experienced at emergency braking. Experience does not necessarily equate to skill, and skill in one area may not equate to skill in another area. On the other hand, the data does appear to show that antilock brakes (particularly with linked or integrated braking systems) help riders achieve higher levels of deceleration more consistently, and much of this benefit (at least the consistency part) is likely to carry over to emergency braking in the face of actual emergencies.

A Review of the Studies

Tolhurst and McKnight tested and compared five methods of braking in a straight line and three methods of braking in a curve [2]. For all eight methods, the rider applied the front brake to the maximum extent possible without locking the wheel. For the straight-line braking tests, which were run from a nominal speed of 40 mph, the method of rear wheel braking varied as follows: no rear wheel braking, light rear wheel braking, locked rear wheel braking, pumping of the rear brake, and heavy rear wheel braking just below the level necessary to lock the wheel. For the tests related to braking in a curve, which were run from a nominal speed of 30 mph, the method of rear wheel braking varied as follows: no rear wheel braking while keeping the motorcycle leaned, heavy rear wheel braking while keeping the motorcycle leaned, and heavy rear wheel braking while righting the motorcycle.

This study utilized three expert riders

operating three different motorcycles – a Yamaha FJ1100 (a sport touring motorcycle), a Yamaha 550 Vision (a standard motorcycle), and a Suzuki GS 550 (a standard motorcycle). For the straight-line braking, adding the heavy rear wheel braking to the front wheel braking (below the level necessary to lock the wheel) produced the highest deceleration and the shortest stopping distance. The lowest deceleration and longest stopping distances resulted when only the front brake was applied. This study did not examine rear wheel only braking. For braking in a curve, the highest deceleration and shortest stopping distances were achieved by righting the motorcycle while applying heavy braking to both brakes (without locking the wheels). The lowest deceleration and longest stopping distances were generated by continuing to lean in the curve and not applying any rear brake.

*Tolhurst and McKn*ight noted that there were *"highly significant differences among the three [riders]…[these] differences are more easily attributed to differences in the design of motorcycle, particularly the tire 'footprint,' than to the skill of the riders."* These authors only reported a single average stopping distance for each braking method, and so their article does not enable deeper analysis of motorcycle-to-motorcycle or rider-to-rider differences. These authors also noted that *"applying both brakes just short of lock-up can demand a high degree of braking skill. Less proficient riders might find one of the alternative methods to be more effective for them."* Given that this study utilized expert riders, the decelerations reported are unlikely to be achieved by the average rider.

Prem conducted *"emergency straight-path braking"* tests with 59 volunteer riders. He used the Motorcycle Operator Skill Test (MOST) to provide a quantitative assessment of the riders' skill level [3, 4]. The MOST takes the riders through a series of tasks designed to test their steering and braking performance. The braking maneuver from this test required the riders to brake aggressively to a stop from a speed of 32 kph (20 mph). A red signal light was activated to indicate to the riders when they should begin braking. The motorcycle used by the volunteers, a Honda CB400T, was instrumented to record the rider's front and rear brake-lever force inputs and motorcycle speed.

Prem analyzed differences in braking technique between skilled and less-skilled riders. He found that skilled riders applied higher levels of front brake force than the less -skilled riders. Less-skilled riders preferred the use of the rear brake. The skilled riders also modulated the level of front and rear wheel braking to maintain optimum braking as weight shifted towards the front of the motorcycle during heavy braking. The less-skilled riders maintained a generally constant level of pedal pressure independent of the weight shift. More skilled riders also exhibited shorter braking reaction times, though it should be kept in mind that this reaction was to an illuminating light that the riders knew would illuminate, not to an actual emergency situation.

Fries, Smith, and Cronrath performed testing with five different motorcycles to determine the deceleration of the motorcycles when the rider employed the rear brake only and when a combination of front and rear braking was employed [5]. They tested a 1968 Harley-Davidson FLH (a touring motorcycle), a 1978 BMW R90 (a standard), a 1982 Honda XR500R (a dirt bike), a 1972 Honda SL350 (a standard), and a 1972 Honda SL125S (a standard). Each motorcycle was tested at nominal speeds of 20, 30, and 40 mph (32.2, 48.3, and 64.4 kph) on worn asphalt. The experience level of the riders was not reported in the study. Overall, the deceleration from rear only braking was less than when heavy front braking was also used. The range of deceleration for rear only braking was 0.31 to 0.52g. The range of decelerations when heavy front wheel braking was also employed was between 0.54 and 0.88g.

These authors observed that *"when faced with an emergency stopping situation, or avoidance situation, a motorcycle [rider] has the decision of whether to stop using the rear brake only, front and rear brakes combined, or by laying the motorcycle down. There are several common misconceptions about motorcycles. One is that they will stop faster if they are laid down on their side…When a motorcycle is stopped by laying it on its side there is a delay in implementing the deceleration…The test results show that laying a motorcycle over and rear wheel braking have very similar deceleration factors. However, when laying a motorcycle over there is an impact and risk of injury when the motorcycle hits the pavement. Also, all control is lost. If the motorcycle is kept upright, it is possible to reduce braking and steer. Front and rear wheel braking provides the best deceleration factors. Our testing also demonstrates that even during hard braking with front and rear brakes, the experienced driver consistently maintained a straight path without causing the motorcycle to fall."*

On the other hand, it should be acknowledged that the riders in this study were not confronted with an actual emergency, and thus, had a different level of urgency than that which riders in real crash scenarios might be confronted. In some crash situations, riders will not be able to avoid a collision regardless of the deceleration they are able to achieve. In these situations, it is not unusual for riders to unintentionally lay the motorcycle down by over-braking the front brake.

Hunter reported acceleration and braking tests conducted by the Washington State Patrol on a dry, level roadway with a 1983 and a 1985 Kawasaki 1000 police motorcycle [6]. For deceleration tests with rear braking only, Hunter reported decelerations between 0.35 and 0.36g. For deceleration tests with front braking only, *Hunter* reported decelerations between 0.64 and 0.74g. For deceleration tests with heavy front and rear braking, Hunter reported decelerations between 0.63 and 0.96g. For the rapid acceleration tests, *Hunter* reported accelerations between 0.48 and 0.73g. He did not specify the experience level of the riders who conducted these tests, although he indicates that they both worked for the Washington State Patrol (presumably they were experienced motor officers). In the discussion, this paper observes that *"overall operator skill has a great influence on the deceleration ability of the motorcycle."*

Hugemann and Lange conducted 74 instrumented braking tests with 18 different riders, 15 of whom were riding their own motorcycle [7]. Motorcycle types were not specified. The riders had varying levels of experience (less than 12,500 miles and up to 80,000 miles) and were instructed to brake from 50 kph (31 mph) to a standstill *"within the shortest possible distance."* The tests were conducted on dry asphalt. Riders characterized as *"skilled"* exhibited mean decelerations between 0.70 and 0.81g. Riders characterized as *"novice"* exhibited decelerations between 0.44 and 0.52g. Individual test results were not reported in this article.

Bartlett reported testing with four motorcycles – a Harley-Davidson FXRT, a Yamaha FZ600, a Suzuki Katana 750, and a Kawasaki EX650 [8]. For tests that utilized only the rear brake, the maximum decelerations between these four motorcycles varied between 0.38 and 0.46g. For tests that utilized only the front brake, the maximum decelerations varied between 0.88 and 0.89g. *Bartlett* reported testing with combined front and rear braking for the Harley-Davidson. This produced a maximum deceleration of 0.96g. In this testing, the Yamaha brake pads were deteriorated, resulting in metal-to-metal contact. The maximum deceleration produced with the Yamaha with these deteriorated brake pads was 0.75g. The experience and skill levels of the test rider was not reported in this study.

Ecker and his colleagues [9] conducted a study comprised of approximately 600 tests performed by more than 300 riders of varying levels of experience (novice to 40+ years) operating an instrumented Honda CB500. Most of the riders were participants in motorcycle safety courses. As the riders were operating the Honda around a training facility, the test coordinator would trigger a red light mounted to the instrument cluster, signaling the rider to *"make a full stop emergency braking maneuver."* The authors noted that *"the test persons were aware of the imminent signal to start the maneuver. However, the test coordinator could vary the instant of triggering the maneuver via remote control within several seconds so that there was some uncertainty involved for the test persons."* These tests were conducted on dry asphalt from a speed of approximately 60 km/h (37 mph). The average deceleration for all 600 runs was 0.63g with a standard deviation of 0.12g. One conclusion of this study was that *"a correlation between experience and deceleration is hardly recognizable, especially for more than 1 year of riding experience."* Another conclusion was that half of the tested individuals utilized 56% or less of the deceleration that could be achieved with the motorcycle.

Vavryn [10] examined the influence of rider experience level and the effectiveness of antilock braking systems (ABS). He reported the results of 800 tests performed with 181 subjects on two different motorcycles. The riders were asked to "come to a complete stop as soon as possible without falling off the vehicle." Initial speeds were either 50 or 60 kph (31 or 37 mph). The subjects performed two tests on their own motorcycle and then two runs on a motorcycle equipped with ABS. One of the ABS-equipped motorcycles was a standard-style BMW and the other was a scooter equipped with linked ABS. The average deceleration for experienced motorcyclists on their own motorcycle was 0.67g (SD = 0.14g). When riding the motorcycles equipped with ABS, that number jumped up to 0.80g (SD = 0.11g). Eighty five percent of the subjects exhibited improved braking with the ABS-equipped motorcycle and the novice riders achieved almost equal braking decelerations to the experienced riders when operating the ABS-equipped motorcycles. Vavryn also noted that *"the deceleration the novice drivers achieved with ABS almost equals the experienced drivers' deceleration. All of the novices improved their deceleration with ABS."* Without ABS, the novice riders achieved an average deceleration of 0.57g.

Bartlett, Baxter, and Robar reported hundreds of brake tests from reconstruction classes conducted at the Institute of Police Technology and Management (IPTM) from between 1987 and 2006 [11]. These tests were conducted at various locations around the country with 112 different motorcycles and riders. They were conducted on dry asphalt or concrete. Initial speeds in the tests were nominally 20, 30, and 40 mph (32.2, 48.3, and 64.4 kph). The riders in these tests were typically motorcycle unit officers or instructors from a police agency. Thus, this study was of experienced riders operating in parking lots. The data in this study included 275 rear brake only tests, 239 front brake only tests, and 221 tests with combined front and rear braking. This data yielded the conclusion that the decelerations were normally distributed with a mean and standard deviation for the rear only braking of 0.37g ± 0.06g, with front only braking of 0.60g ± 0.16g, and with combined front and rear wheel braking of 0.74g ± 0.15g.

Bartlett and Greear [12] presented brake test data from students in a motorcycle training program (Skills Training Advantage for Riders from the State of Idaho) with three skill levels – Basic I, Basic II, and Experienced. The authors noted that *"the Basic I program is for riders who are new to motorcycling, with virtually no experience, and is conducted on STAR training motorcycles. These bikes are typically 250cc or smaller, with front disc and rear drum brakes. The Basic II program is for riders who are returning to motorcycling or those who have* *ridden on dirt, but not on the street, i.e., riders with some experience but not much on street cycles. These riders also use the program's training motorcycles. The Experienced program is for riders who have been riding for more than one year and is conducted using the riders' own motorcycles."*

The culmination of each program was a riding skills test, which included a stopping test conducted in a parking lot. Riders were instructed to approach the stopping area at a steady speed between 15 and 20 mph (24.1 and 32.2 kph). Once in the stopping area, they were to stop the motorcycle as quickly as they could with maximum braking. Bartlett reported the results of 288 tests, close to 100 tests for each experience level. The results of these tests *"were almost indistinguishable"* for the three skill levels. The Basic I group produced decelerations with a mean and standard deviation of 0.60g ± 0.16g, the Basic II group produced decelerations of 0.64g ± 0.14g, and the Experienced group produced decelerations of 0.61g ± 0.14g. When the experience levels were combined into one dataset, the decelerations were 0.62g ± 0.15g. In this study, no information was reported about the front-to-back braking split used by each rider or about the braking systems on the motorcycles for the tests where the students use their own motorcycles. The summary of braking data included below assumes that the riders in this study generally used both brakes and that the motorcycles did not have antilock brakes.

Dunn [13] reported brake test data and tire mark characteristics for three motorcycles – a 1995 BMW R1100RS (sport-touring with antilock brakes), a 2003 Buell XB9R (sport), and a 2005 Harley-Davidson XL 1200 Sportster Custom (cruising/touring). They tested three different braking strategies – best effort front braking only, best effort rear braking only, and best effort front and rear combined braking. Initial speeds for the tests were nominally 25, 45, and 60 mph (40.2, 72.4, and 96.6 kph) and most of the tests were conducted on a flat, dry asphalt surface. One set of tests was conducted on wet asphalt with the BMW, a motorcycle equipped with antilock brakes. The riders used in this study varied in years of experience, from 2 years to 35 years. Nothing was reported regarding the annual mileage covered by the riders.

For the BMW, the rear-braking-only strategy produced decelerations between 0.364 and 0.416g. The front-braking-only strategy produced decelerations between 0.671 and 0.828g. The combined front and rear braking strategy produced decelerations between 0.642 and 0.842g. For all three strategies, the decelerations increased with increasing speed. On the wet asphalt surface, the BMW produced decelerations with both brakes between 0.637 and 0.827g. For the Buell, the rear-braking-only strategy produced decelerations between 0.345 and 0.380g. The front-braking-only strategy produced decelerations between 0.548 and 0.709g. The combined front and rear braking strategy produced decelerations between 0.612 and 0.708g. Again, for all three strategies, the decelerations increased with increasing speed. For the Harley-Davidson, the rear-braking-only strategy produced a deceleration of 0.386 (this strategy was only tested at 45 mph). The front-braking-only strategy produced a deceleration of 0.518g (this strategy was only tested at 45 mph). The combined front and rear braking strategy (tested at 45 and 60 mph) produced decelerations between 0.658 and 0.674g.

Dunn found that *"at the extreme, the rear tire of the Buell lifted off the ground in some tests." Frank* [14] noted that *"pitch-over events are common in motorcycle accidents and can be caused by impact to the front wheel and occasionally by hard brake application... Provided there is sufficient tire/road friction, at the limit of the braking capacity of the motorcycle the weight on the rear tire is zero. Though not inevitable, this is the point at which the motorcycle can pitch-over." Frank* conducted 18 sled tests to evaluate the trajectory and velocity of riders and passengers on motorcycles that pitched over due to braking. This testing used target decelerations of 1.0, 1.15, and 1.3g. Target speeds for the testing were 20, 30, and 33.5 mph (32.2, 48.3, and 53.9 kph). The lowest braking deceleration that produced a pitch-over in *Frank's* testing was 1.0g with a test speed of 30.2 mph (48.6 kph).

Fatzinger, Landerville, Bonsall, and Simacek [15] reported a study of motorcycle deceleration for sport motorcycles during over-braking of the front wheel. Testing was conducted with the following motorcycles: a 2002 Kawasaki ZRX1200R, a 2006 Yamaha YZF-R6, and a 2013 Ninja EX300. Thirteen tests were completed, with initial speeds ranging from 50 to 60 mph. All three motorcycles had independently actuated front and rear brakes without antilock brakes. Testing was conducted on a flat asphalt surface. Brake pressure was applied to the front brake lever or the rear brake pedal with elastic straps. Electronically controlled valves installed in each brake line prevented this pressure from being applied to the calipers until the motorcycle was up to speed. Of the 13 tests, 3 were performed with a 6 ft, 1 in and 175 lb dummy on the motorcycle. In some of the tests, rear wheel braking was applied in addition to the front braking, and in some of the tests, no rear braking was applied. Front wheel lockup was achieved in 9 of the tests.

Fatzinger et al reported that the deceleration achieved by the motorcycle with front wheel lockup depended on the lean angle of the motorcycle at the beginning of the braking. They reported that the average deceleration when the initial lean was approximately 2 degrees or less was in the range of 0.69 and 0.8g. The average deceleration when the initial lean was around 3 or 4 degrees was between 0.51 and 0.67g. The average deceleration when the initial lean angle was between 8 and 9 degrees was 0.32 to 0.39g. When the front wheel braking resulted in a pitch-over, the deceleration was in the range of 0.8 to 0.86g. Rear brake application did not significantly increase the deceleration of the motorcycles when front wheel lock had been achieved. Also, there were *"no significant differences noted in the peak and average decelerations between the tests"* with and without the dummies.

Peck, Deyerl, and Rose examined the effect of tire pressure on the deceleration achieved with full application of the rear brake only [16]. This testing utilized a 2003 Suzuki GSF1200 equipped with Michelin Pilot Road radial tires. The tests were run from a nominal speed of 30 mph (48.3 kph) – three tests with the rear tire at 40 psi and three tests with the rear tire at 20 psi. The front tire was inflated to the manufacturer recommended tire pressure of 36 psi for all tests. These authors documented the size of the tire contact patch by using a rear swingarm stand to suspend the rear tire above a piece of brown paper, putting paint on the tire, and then lowering the tire onto the paper. The size of the rear tire contact patch was 46% larger at 20 psi than at 40 psi and the average deceleration was 5% greater at 20 psi than at 40 psi. For the tests at 40 psi, the three tests yielded the following decelerations (g): 0.324, 0.321, and 0.327 (average = 0.324). For the tests at 20 psi, the three tests yielded the following decelerations (g): 0.341, 0.339, and 0.338 (average = 0.339). These findings related to the influence of tire pressure are consistent with results reported by others for passenger cars [17, 18].

Table 1 summarizes the decelerations from the studies reviewed here. These decelerations can potentially be applied for calculating a motorcycle's speed loss due to maximal braking by the operator or for assessing a motorcyclist's ability to avoid a crash. The reconstructionist will need to consider conditions relevant to each particular crash. For example, what evidence is there related to the braking strategy rider utilized (rear only, front only, or front and rear combined)?

Study	Best Effort Braking Decelerations on Dry Roadway (g)			
	Rear Brake Only (No ABS)	Front Brake Only (No ABS)	Front and Rear Combined (No ABS)	Front and Rear with ABS
Tolhurst and McKnight [5] (expert riders)		0.77	0.97	
Fries, Smith, and Cronrath [8]	0.31 to 0.52		0.54 to 0.88	
Hunter [9] (experienced riders)	0.35 to 0.36	0.64 to 0.74	0.63 to 0.96	
Hugemann and Lange [10]				
Bartlett [11]	0.38 to 0.46	0.88 to 0.89	0.96	
Ecker [12] (mixed experience levels)			0.63 ± 0.12	
Vavryn [13]			0.67 ± 0.14	0.80 ± 0.11
Bartlett, Baxter, Robar [14] (motor officers)	0.37 ± 0.06	0.60 ± 0.16	0.74 ± 0.15	
Bartlett and Greear [15] (students)			0.62 ± 0.15	
Dunn, et al [16]	0.345 to 0.386	0.518 to 0.709	0.612 to 0.708	0.642 to 0.842
Fatzinger, et al [18]		0.69 to 0.80		
Peck and Deyerl [19]	0.321 to 0.341			
Summary (min to max)	0.31 to 0.52	0.52 to 0.89	0.54 to 0.96	0.64 to 0.842

Table 1 – Summary of braking decelerations from various studies (dry pavement)

Studies for Motorcycles with Integrated and Antilock Brakes (ABS)

This section reviews additional studies that focused on motorcycle braking systems equipped with integrated front and rear brakes or antilock brakes. These studies provided illustrative results of the influence of these systems, but these systems vary in how various manufacturers implement them. Reconstructionists can refer to the owner's manual for specific motorcycles for information specific to individual motorcycles. Individual motorcycles can also be tested.

Mortimer examined the effectiveness of integrated brakes on a motorcycle without ABS [19]. His testing utilized a 1979 Yamaha XS-400 with standard brakes as the original equipment and a 1982 Yamaha XS-1100 with integrated brakes as the original equipment. Mortimer modified both motorcycles so that they could be operated in either a standard braking mode or an integrated braking mode. The integrated mode on the XS-400 could only be operated with the right-side rear brake foot pedal. On the XS-1100, the integrated braking would be activated with either the right-side foot pedal or hand lever. Five experienced riders were used. Tests were run from a nominal speed of 25 mph (40.3 kph), and the riders attempted to stop the motorcycle in as short a distance as possible. Each rider performed testing on each motorcycle, and they made five stops in each test condition. The tests were run with the hand brake only, the foot brake only, and then both.

Mortimer noted that *"the stopping distances were directly measured at the point where the motorcycle came to a stop in terms of the distance from the cones marking the entrance to the braking course. The stopping distance was translated into the mean deceleration during the stop, assuming an initial speed of 40.3 km/h."* This manner of measuring the stopping distance and deceleration is prone to error since there is no way to know, in any given instance, if the riders began braking at the cone or to know that the rider started braking from a speed of precisely 40.3 kph (25 mph). *Mortimer* found the greatest benefit from integrated brakes for the condition of braking with the foot pedal only. He noted that *"use of the foot brake alone of the XS-400 motorcycle produced a 72% greater mean deceleration in the integrated than the separated mode. Similarly, use of the foot brake of the XS-1100 motorcycle in the integrated mode produced a 50% increase in mean deceleration compared with the separated mode…In addition, when both brakes were used on the larger motorcycle there were significant and consistent increases in deceleration obtained on both the dry and wet pavements in the integrated mode* *compared with the separated mode, but the increments were not as large as those found for the operation of the foot brake alone."*

As mentioned in the prior section, *Vavryn* [10] examined the effectiveness of ABS, reporting the results of 800 tests performed with 181 subjects on two different motorcycles. The riders were asked to *"come to a complete stop as soon as possible without falling off the vehicle."* Initial speeds were either 50 or 60 kph (31 or 37 mph), and the subjects performed two tests on their own motorcycle, and then two runs on a motorcycle equipped with ABS. One of the ABS bikes was a standard BMW, while the other was a scooter equipped with linked ABS. The average braking deceleration for motorcyclists on their own motorcycle was 0.67g (SD = 0.14g). However, when riding the motorcycles equipped with ABS, that number jumped up to 0.80g (SD = 0.11g). Eighty five percent of the subjects exhibited improved braking with the ABS-equipped motorcycle and the novice riders achieved almost equal braking decelerations to the experienced riders when operating the ABS-equipped motorcycles.

Green reported a test program conducted by NHTSA, in cooperation with Transport Canada (TC), *"to assess the effectiveness of anti-lock braking systems (ABS) and combined braking systems (CBS) on motorcycles"* [20]. Six motorcycles were tested on both dry and wet asphalt – a 2002 Honda VFR 800 with ABS and CBS, a 2002 BMW F650 with ABS, a 2002 BMW R 1150R with ABS and CBS, a 2002 BMW R 1150R without ABS or CBS, a 2004 Yamaha FJR1300 with ABS, and a 2004 Yamaha FJR1300 without ABS. Green observed that, with ABS, *"the stopping distances were very consistent from one run to another."* Without ABS, *"the stopping distances were less consistent because the rider while modulating the brake force, had to deal with many additional variables at the same time…Test results from non-ABS were noticeably more sensitive to rider performance variability."* On average, ABS reduced the stopping distances by approximately 5%.

Anderson, Baxter, and Robar [21] reported deceleration testing of motorcycles with the following different braking systems: standard brakes (1990 Harley Davidson Road King FLHTPI), integrated brakes without ABS (1986 Yamaha Venture Royale XVZ13), independent ABS brakes (1999 BMW R1100RPT), integrated ABS brakes, and linked brakes (2003 Honda VFR800 Interceptor). The authors tested each of these systems on an asphalt surface (automobile 0.83) with application of the rear pedal only, the front lever only, and with both levers applied. The initial speed for the tests was approximately 56 kph. All the tests utilized the same operator with many years of riding experience. The authors noted that *"there was no wheel lockup or skidding during any of the tests runs."*

Table 2 summarizes the results of the testing for each braking system. The values in this table are primarily of use for showing the comparison between the different braking systems. This study used only a single experienced rider and the variability in decelerations from test-to-test was not reported. Thus, the values in this table should not be blindly applied to a reconstruction, without consideration of how a typical rider would perform with each system. In addition, the authors noted that *"this testing only analyzed motorcycle braking during the period of maximum, and near-constant, deceleration. Operator reaction time and brake system lag time were not addressed in this study, although such investigation may be worthwhile as extensions of the work presented in this paper. The systems that utilize linkages to actuate both front and rear brakes, such as the integrated and linked brakes of the BMW and Honda motorcycles herein, may have lag times and mechanical behavior that affects the resultant onset of deceleration."* The trend in these values is, however, consistent with the benefits that would be expected from the various braking systems.

Average Deceleration (g)					
	Standard	Integrated	ABS	Integrated ABS	Linked
Pedal Only	0.42	0.58	0.40	0.98	0.62
Hand Lever Only	0.65	0.74	0.89	0.92	0.86
Both Levers	0.71	0.88	0.93	1.00	0.93

Table 2 – Summary of average braking decelerations for various systems [21]

	Rear Brake Only	Front Brake Only	Front and Rear Combined
ABS Off	0.37	0.79	0.79
Race Mode ABS	0.40	0.80	0.80
Sport Mode ABS	0.38	0.76	0.72

Table 3 – Average decelerations reported by Dinges and Hoover [21]

Anderson, Baxter, and Robar concluded that *"motorcycle braking systems that actuate both front and rear brakes with the application of only one control lever produce more effective braking than independent front and rear brakes on a standard system. When combined with anti-lock control the benefits of the combined system are increased. Perhaps more importantly, however, is that the motorcycle is also more stable during the braking maneuver. The increased stability along with the simplified brake application combine to reduce the load on the operator during the stressful moment of hard braking to avoid a crash. The operator does not have to concentrate on modulating pressure between two separate controls and simultaneously keep the motorcycle stable and prevent the wheels from locking, as the system performs these functions and permits the operator to focus on avoiding the crash."*

Dinges and Hoover [22] reported a series of maximal braking tests on a dry, asphalt surface with and without the antilock brakes active on a 2011 BMW S1000RR (a super sport motorcycle). This motorcycle was tested in three modes related to the ABS – sport mode, race mode, and ABS disabled. The BMW was equipped with partially integrated braking when the ABS was active. When the ABS was deactivated, the integral braking was also deactivated. These authors reported a coefficient of friction for the test surface of 0.7, measured using a Ford Expedition with the ABS disabled. Their testing yielded 420 braking runs, with target speeds ranging from 40 to 60 mph. *Table 3* lists the average decelerations reported by Dinges and Hoover for each mode with three braking conditions – rear brake only, front brake only, and front and rear braking combined. In addition to these decelerations, Dinges and Hoover reported hydraulic pressure build times, noting that "the average time it takes to build pressure in the front brake system is between 0.2 and 0.3 seconds…The rear brake system is similar, but a range of 0.2 to 0.4 seconds is shown from the data."

Avoidance Analysis

Crash reconstructionists are frequently asked to determine how a crash could have been avoided. This analysis will typically require an assumption about the level of deceleration a motorcyclist should have been able to achieve. Based on the data summarized in *Table 1*, motorcyclists would typically be able to achieve a deceleration of 0.5g and above on a dry road by utilizing only their front brakes (with a conventional motorcycle braking system). By utilizing both brakes, most motorcyclists will be able to achieve a deceleration of 0.6g and above on a dry road (again, with a conventional motorcycle braking system). With antilock brakes, particularly if there is integration between the front and rear brakes, motorcyclists are likely to achieve higher decelerations with greater consistency than they would have with a motorcycle with a conventional braking system.

That said, the level of deceleration that can be achieved during a specific emergency must consider conditions present that may have affected a rider's ability to achieve these expected levels. External factors such as roadway conditions, other traffic, the presence of cargo or passengers, or what the specific avoidance decision a rider makes may need to be considered when assigning an expected braking level to a specific crash scenario. Also, studies have shown that drivers and riders do not necessarily utilize their full deceleration capabilities when trying to avoid a crash [23, 24].

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Impact

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As ever, the Editor would be very pleased to hear from members, non-members or subscribers, who have produced material that they feel would be of interest to readers of *'Impact'*. Details of research projects or relevant collision investigation testing would be particularly welcome. Attracting sufficient numbers of articles for publication in the Institute's journal remains a difficulty! Whilst the Editor is delighted to receive papers from overseas contributors, a greater supply of 'home grown' material would also be very welcome.

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Distracted Driving: What we know and how psychological research can help collision investigations

Dr. Gemma Briggs
Head of Discipline and Senior Lecturer in Psychology

As an applied cognitive psychologist, and Senior Lecturer in psychology at The Open University, my area of research interest and expertise is driver distraction. Specifically, I am interested in how drivers allocate their attention when they try to multitask behind the wheel. Most of my work looks at mobile phone use by drivers, one of the so-called fatal 4 behaviours which the police target to improve road safety. I have worked extensively with the police, road safety charities, members of industry and policy makers to promote education and evidence-based practice in the area of distracted driving.

I first became interested in this area of research as an undergraduate student when I read a study which found that drivers who used their phones were around 4 times more likely to crash than undistracted drivers [1]. This statistic alone was relatively shocking, but the part that fascinated me most was the finding that this increased crash risk persists for around 5 minutes after a phone conversation has ended. This suggests that far from phone use being a purely manual issue, involving taking the hands from the wheel and the eyes from the road, there must be other cognitive issues at play. My own research has focused on identifying what those cognitive roots to distraction may be and providing explanations for why such cognitive distraction results in deteriorated driving performance [2][3][4]. As such, the work that I have carried out focuses on hands-free phone use.

This is a relatively contentious and perhaps inconvenient research position, given that in the UK only handheld phone use is illegal. However, research from over 20 years has categorically demonstrated that hands-free phone use offers no safety benefit over hand held: any type of phone use leads to increased crash risk [5], poor hazard perception [6], increased reaction times for any hazards that are detected [7], and generalised reduction in a driver's situational awareness [8]. As such, while a worrying trend of increasing numbers of drivers admitting to flouting the law is of course a pressing issue to address, so too is the fact that many drivers who are legally distracted behind the wheel are contributing to increased danger on the roads. With self-reported phone use increasing [9][10] and no year-on-year reductions in the number of individuals being killed or seriously injured on UK roads [11], driver distraction poses a significant safety challenge.

My work with police practitioners sheds further light on the issues of enforcing current mobile phone law, whilst also not promoting hands-free phone use as a 'safe' alternative. While the UK government has made assurances that current legislation will be changed to make clear exactly what phone use constitutes, the current position is that a handheld phone used for an interactive communicative function constitutes illegal phone use. This places the burden of proof onto police officers: if they see someone using their hand-held phone, they need sufficient evidence to ascertain the function it is being used for in order to prosecute the driver. Only those incidents where it is possible to gain such evidence are aligned to the contributory factor of 'phone use/in vehicle distraction' (meaning that the number of recorded incidents linked to phone use most likely underrepresent the true scale of the problem). Handsfree phone use, of course, is not recorded as a contributory factor (although a handsfree phone using driver can be prosecuted for driving without due care and attention) despite evidence strongly supporting the view that many handsfree phone using drivers may be involved in incidents attributed to 'driver error' and 'failure to look'. This position highlights a hypocrisy in current legislation: it is recognised that interactive engagement with a phone is problematic for drivers, but at the same time this is only focused on the manual, handheld, aspect of phone use. This approach ignores widely shared scientific evidence which demonstrates that having both hands on the wheel and both eyes on the road is not sufficient if the driver also has their mind on a phone conversation. This is something which policy makers are aware of, and indeed recommendations have been made to update mobile phone legislation to bring it inline with scientific research findings [12].

Irrespective of current law, the issue of recording the scale of incidents attributed to phone use is clear. Similar challenges are present for those who are tasked with investigating the aftermath of collisions, in an attempt to explain exactly what happened. Here the gathering of evidence is obviously of great importance in piecing together the details of an individual event. While mobile phone records and witness statements may go some way to identifying a contributory factor of driver distraction, psychological research findings can also be meaningfully applied to add further explanation or support for a case. For example, the knowledge that a mobile phone need not be handheld or in use at the exact point of collision, for it to have contributed to an event.

I will be discussing some of my research and work with various organisations in a short series of sessions on driver distraction for the ITAI, starting in September. The aim of the sessions is to outline what psychological research on distracted driving can tell us about specific driving detriments and how such findings can help with collision investigations. I look forward to speaking with any members who can attend in September.

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Evaluation of the accuracy of longitudinal speed change reported by event data recorders in frontal crash tests

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Abstract

Event data recorder (EDR) data stored in airbag control modules (ACMs) has been available from an increasing number of North American vehicles over the past 19 years and has become a common part of most North American collision investigations. In order to confidently use the collision severity data reported by EDRs, users need to understand the accuracy and the limitations of the data. In this study, we combined data from 1368 low-speed crash tests we have performed with 105 high-speed crash tests performed by the National Highway Traffic Safety Administration (NHTSA) and Transport Canada in order to evaluate the accuracy of the EDR reported speed change. Over-all, we found that the error in EDR reported speed change was generally less than 5 km/h for collisions with a speed change of less than 55 km/h. For collisions with a speed change greater than 55 km/h, there were manufacturer-specific sources of error that

Introduction

Starting in the year 2000, collision reconstructionists in North America were provided access to a limited amount of crash-related data recorded by an event data recorder (EDR) function in the Airbag Control Modules (ACM) of select General Motors (GM) and then Ford vehicles. In the initial release, the data was primarily limited to the longitudinal speed change or longitudinal acceleration pulse recorded and some airbag deployment parameters. Over time, the amount and types of data have increased substantially and almost all manufacturers have made their data accessible.

The accuracy of the EDR reported speed change has been assessed in numerous studies [1-12], and much of the EDR literature has been recently summarized [13]. Several potential sources of error in the EDR reported speed change have been described or proposed in the literature. Chidester et al. [14] first cited a ±10% accuracy for the speed change in GM vehicles based on the limitations of the accelerometers. Lawrence et al. [1] found that GM ACM's did not begin recording a speed change until a threshold acceleration was reached resulting in an underestimate of the final speed change. Other studies have shown that for the early generation of EDRs, there was limited memory and not all of a crash pulse was being recorded resulting in an underestimate of the final speed change [1,2,12]. Several studies [1, 5] also observed a bias in the accelerometer that resulted in both underestimation and overestimation of the reference speed change in a crash.

Specific to higher speed crashes, Tsoi [12] discussed two different potential sources of error. The first source of error was potential damage to the ACM or its mount position. Many ACM's are mounted on the center tunnel under the center instrument stack and can be exposed to potential contact in high severity collisions with footwell area intrusion. The second source of error was clipping of the accelerometer signal in the ACM. This clipping, also discussed in a report prepared by Exponent for Toyota [15], suggested clipping could occur at 50g accelerations due to a limitation of the accelerometers. The Exponent report also showed evidence of ACM mount damage in higher severity crash tests.

Objective

The objective of this paper was to investigate the proposed sources of error in the speed change reported by EDRs across a range of manufacturers and collision severities.

Methods

This study relies on 1368 vehicle crash tests or crash tests replicated on a linear sled with speed changes below 20 km/h performed by our company (MEA Forensic) and 105 vehicle crash tests between 40 and 70 km/h performed by the National Highway Traffic Safety Administration (NHTSA) and Transport Canada. All tests involved vehicles made between 1997 and 2017 for sale in North America.

MEA Tests

The majority of the MEA tests (n = 1362) consisted of multiple series of vehicle-to-barrier impacts, vehicle-to-vehicle impacts and vehicle collision pulses replicated on a linear sled. Tests were performed using EDR equipped vehicles over a range of model years (9 GM models, 2 Ford models and 11 Toyota models).

Table 1: Vehicle models used in low speed crash tests.

Year	Manufacturer	Model
1996, 1999	Pontiac	Sunfire
1997, 1998, 2003, 2004	Chevrolet	Cavalier
2003, 2004	Chevrolet	Impala
2004	Chevrolet	Trailblazer
2003	Ford	Crown Victoria
2003	Ford	Windstar
2005, 2006, 2010, 2013	Toyota	Corolla
2005, 2008, 2015	Toyota	Camry
2006, 2007, 2010, 2013	Toyota	Prius

In the vehicle-to-vehicle and vehicle-to-barrier tests, a calibrated 5th wheel (MEA Forensic, Richmond, BC) was mounted to the side of each test vehicle to measure its speed before, during and after the collision. The distance accuracy of the 5th wheel based on comparisons to a surveyor's tape was on average 0.02% and always within 0.1%. A triaxial accelerometer (either an Endevco 7265A; ±100g, San Juan Capistrano, CA or an Analog Devices ADXL250; ±25g, Norwood, MA) was fastened to the ACM mounting bolts using a custom bracket. The accelerometer's sensitive axes were oriented longitudinally, laterally and vertically with respect to the vehicle. The 5th Wheel data were acquired at 256 Hz. Accelerometer data were acquired at 2560 Hz using a 12-bit, simultaneous sample and hold Win30 DAQ card (United Electronics Inc., Watertown, MA). Each data channel conformed to SAE J211, Channel Class 60, with the vehicle accelerometer channel filtered at Channel Class 180 (SAE, 1989). These data were synchronized using a trigger strip mounted to the impact area of the bullet vehicle. In most tests, several ride-along ACMs were mounted in the test vehicles using a custom platform so they were exposed to the same collision pulse. After each test, the EDRs were downloaded using the Bosch Crash Data Retrieval (CDR) system (Bosch Automotive Service Solutions Inc., USA)

The linear sled was instrumented with a uniaxial accelerometer sampled at 2400 Hz (Sensotech 060-F482-04; ± 20g, Columbus, OH). The accuracy of the accelerometer sensor is within ±1%. The linear sled was programmed to reproduce the acceleration profiles measured in the vehicle-to-barrier and vehicle-to-vehicle tests.

Government Testing

NHTSA and Transport Canada crash test data were obtained through the online NHTSA crash test database and Transport Canada publications [8,9]. There were 108 tests with model years ranging from 1998 to 2017 (Table 2). The dataset includes 41 GM vehicles (22 models), 11 Fiat-Chrysler vehicles (10 models), 9 Ford vehicles (7 models), 12 Honda vehicles

(7 models), 27 Toyota vehicles (13 models), 6 Mazda vehicles (3 models), 1 Nissan vehicle, and 1 Volvo vehicle.

The EDR reported speed change was taken from the associated CDR download report on the NHTSA website or as reported by Transport Canada. The reference speed change value came from accelerometers mounted in the test vehicles. The NHTSA test accelerometer data was obtained using the NHTSA Signal Browser software (version 6.17.12.8). The accelerometer positions varied depending on the vehicle. When possible, a test accelerometer mounted at the center of gravity of the vehicle was chosen. When this accelerometer position was not chosen, the signals were taken from the rear sill, the rear floor pan or the rear seat frame. Symmetrical pairs of accelerometers (left and right side), were chosen for vehicles with no accelerometer at the center of gravity. The speed change calculated from the accelerometers was averaged. Accelerometers located towards the rear of the vehicle were chosen to avoid any direct contact due to the collision.

Data Reduction

The speed change of the collisions measured by or calculated from the reference instrumentation were compared to the severity reported by the ACMs. For the 5th wheel data, speed change was calculated as the difference between post-impact and pre-impact speeds. For the accelerometer data, the longitudinal signal was integrated over the collision duration using the trapezoid rule. The percent error in reported speed change was calculated relative to the reference speed change. The accelerometer signals were filtered in two different ways to look at peak accelerations.

One method relied on the 60Hz CFC filter provided in the NHTSA Signal Browser software. The other method filtered the raw data using either a 60 Hz or a 400 Hz Butterworth filter for evaluating the effect of signal clipping.

Two accelerometer clipping models were used to assess whether clipping was a potential source of uncertainty in high speed change collisions. The saturation model set all acceleration values over the set clipping threshold equal to the clipping threshold before integrating the signal. The loss model set all acceleration values over the clipping threshold to zero before integrating the signal.

Results

Low Speed Crashes

In frontal crashes that generated low speed changes (dV< 20 km/h), all of the vehicles and ACMs tended to underestimate the reference speed change (Figure 1). Outside of 4 anomalous tests with a 2003 Chevrolet Cavalier [3], the speed change error ranged from an under-estimate of 5.2 km/h to an overestimate of 1 km/h. The error was much greater than 10% at low speed changes (Figure 1), mostly due to the small denominator in the error calculation.

High Speed Crashes

In the higher speed crashes, the EDR reported speed change could overestimate (maximum 3.3 km/h, 6% error) or underestimate (maximum 18.7 km/h, 29% error) (Figure 2, Table 2). For the crash tests with speed changes between 40 and 55 km/h, the majority of the EDR reported speed changes were within 5 km/h of the reference and therefore had less than 10% error (Figure 3, Figure 4). One crash test of a 2014 Honda Odyssey was an outlier at a 16% error (NHTSA test # 8791). For the crash tests with speed changes above 55 km/h, the magnitude of the errors ranged from an overestimate of 3.3 km/h to an underestimate of 18.7 km/h. There were 21 tests with speed change errors greater than 10%: eight GMs (≤13.5%), six Toyotas (≤29%, five Hondas (≤24%), one

Mazda (23%) and one Fiat (12%). The most accurate EDRs were in the Fords (≤6%).

Sources of Error

In the low speed crashes, the errors were more than the ±10% proposed based on the limitation of the accelerometers. A threshold acceleration at which the EDR starts to record the event is the primary source of this error (Figure 5, see references 1,3-5). Moreover, many new generation EDRs do not record collisions with a speed change of less than 8 km/h, so the range with the highest percent error is eliminated. In some older model ACMs, there was limited memory capacity that could truncate the collision pulse [2]. Finally, a small bias applied to the accelerometer signal was found in some early GM [1] and Toyota [5] EDRs. In the high speed crashes, the effect of a threshold acceleration is small and the 10% error suggested by Chidester is consistent with the crash data for speed changes between 40 and 55 km/h.

Clipping of accelerometer signals

For some of the crash tests that generate speed changes above 55 km/h, there was a wider range of errors for those with higher peak accelerations, but no clear systematic trend (Figure 6). The majority of the tests had peak accelerations below 50g. so the suggested 50g clipping model by Tsoi would only potentially apply to the Toyota and Honda models. There were three different Honda ACMs represented in the data set. They were labelled in the download reports as the SRS K-Line, the GEN 2 and the F-CAN. There was no accuracy trend between the ACMs. The F-CAN EDRs were unique in that they captured two events in all but one of the single impact crash tests. The first crash event looked like a barrier crash test pulse (Figure 7), but the second event was simply a gradually increasing speed change over the entire event. The Honda EDRs report longitudinal acceleration values and the F-CAN EDRs did report values over 50g.

The Honda EDR reported speed change data are truncated and do not match the integrated accelerometer plots. The speed change plateaus at a lower value than the reference speed change, but also reaches a peak in a shorter time (Figure 7). The saturation clipping model was applied, but the saturation acceleration required to result in the reported speed changes was ranged from 20 to 30g and was thus lower than the acceleration values reported by the EDRs. The loss model resulted in a poor match to the speed change plot in the EDR report and also had overly low clipping thresholds of 30 to 50g.

Both clipping models were applied to the Toyota crash tests (Figure 8). When a 50g threshold was used, the loss model yielded a close match to the EDR reported speed change for most of the Toyota tests. For the saturation model, a clipping threshold between 30 and 35g was needed to match the EDR reported speed change. Both clipping models could closely match the shape and magnitude of the EDR reported speed change data.

ACM contact

The largest error in the data set came from a 2012 Toyota Sienna (NHTSA #7615). The reference speed change was 63.8 km/h and the EDR reported a speed change was 45.1 km/h. The peak acceleration recorded by the rear seat accelerometers was -44g on the left and -39g on the right, and therefore a 50g clipping model did not explain the speed change error. Although the post-test condition of the ACM is not discussed in the NHTSA crash test reports, the post-test photographs of the footwell show significant intrusion on the right side of the center tunnel (Figure 9). Since the ACM for this vehicle is mounted under the center instrument stack, buckling of the center tunnel or damage to the ACM mounts could result in incorrect readings and may explain the significant error in the EDR reported speed change [15].

Discussion

The evaluation of EDR reported speed change across a range of manufacturers and collision severities showed that the EDR reported speed change is generally within 5 km/h of the reference speed change for collisions with a speed change of 55 km/h or less (Figure 2, Figure 4). EDR reported speed change error can be greater than 10% in low speed change crashes and in collisions with a speed change greater than 55 km/h. The low-error region for speed changes between about 20 and 55 km/h corresponds to the range at which most airbag deployment decisions are made. In other words, the ACM unsurprisingly appears to be the most accurate in the severity region for which it is primarily designed. The accuracy of the EDR reported speed change in low and higher speed change crashes is less important to its primary function.

The speed change error in the high speed change crash tests varied between manufacturers and between models from the same manufacturer. Many of the vehicle manufacturers use multiple ACM suppliers, so differing trends in accuracy could be due to ACM manufacturer rather than vehicle manufacturer.

In the higher speed crashes, there appear to be several potential sources of error. The suggested accuracy of the accelerometers installed in the devices will be a constant source of uncertainty across all severities. The accelerometers in the GM SDMs reportedly have a 10% uncertainty [14], and this is generally consistent with the errors seen in GM vehicles at high speeds.

One of the proposed 50g accelerometer signal clipping models seems to fit the results of the Toyota crash tests, but it is assumed that accelerations over 50g are not included in the speed change integration. It is difficult to validate this model, which could suggest either a hardware or software issue in the Toyota ACMs. The reference accelerometers are also not proximate to the ACM location and it is unknown how sensitive the ACM is to buckling or vibration of the panels to which it is mounted.

The Honda EDR data displayed a different type of error wherein the crash pulses were truncated and one type of ACM recorded multiple events for one crash. The sources of the error in the EDR reported speed change for Honda vehicles remains uncertain.

Finally, as shown by the Toyota Sienna crash test, damage to the ACM or the area it is mounted can affect the accuracy of the reported data. Toyota ACMs have been shown to sustain mounting tab fractures in high severity collisions [15]. For reconstructionists, this damage may not be readily apparent as the ACM may still be downloadable even if the ACM or its mounts have been damaged. For higher speed change collisions, careful documentation of any intrusion or buckling in the area of the ACM is important.

The findings of this study are limited to the manufacturers, ACMs and speed changes tested. The response of other manufacturers and ACMs at other speed changes is know known. Moreover, the repeatability of some of the data presented here, particularly for the high speed crashes, is not know. Unlike with the low speed change tests, where vehicles can be subjected to dozens of impacts or ACMs can be tested on a linear sled, high speed change crash tests are expensive and generally only done for standardized government testing.

In summary, we found that the error in EDR reported speed change was generally less than 5 km/h for collisions with a speed change of less than 55 km/h. For collisions with a speed change greater than 55 km/h, there were manufacturer specific sources of error that can lead to large errors.

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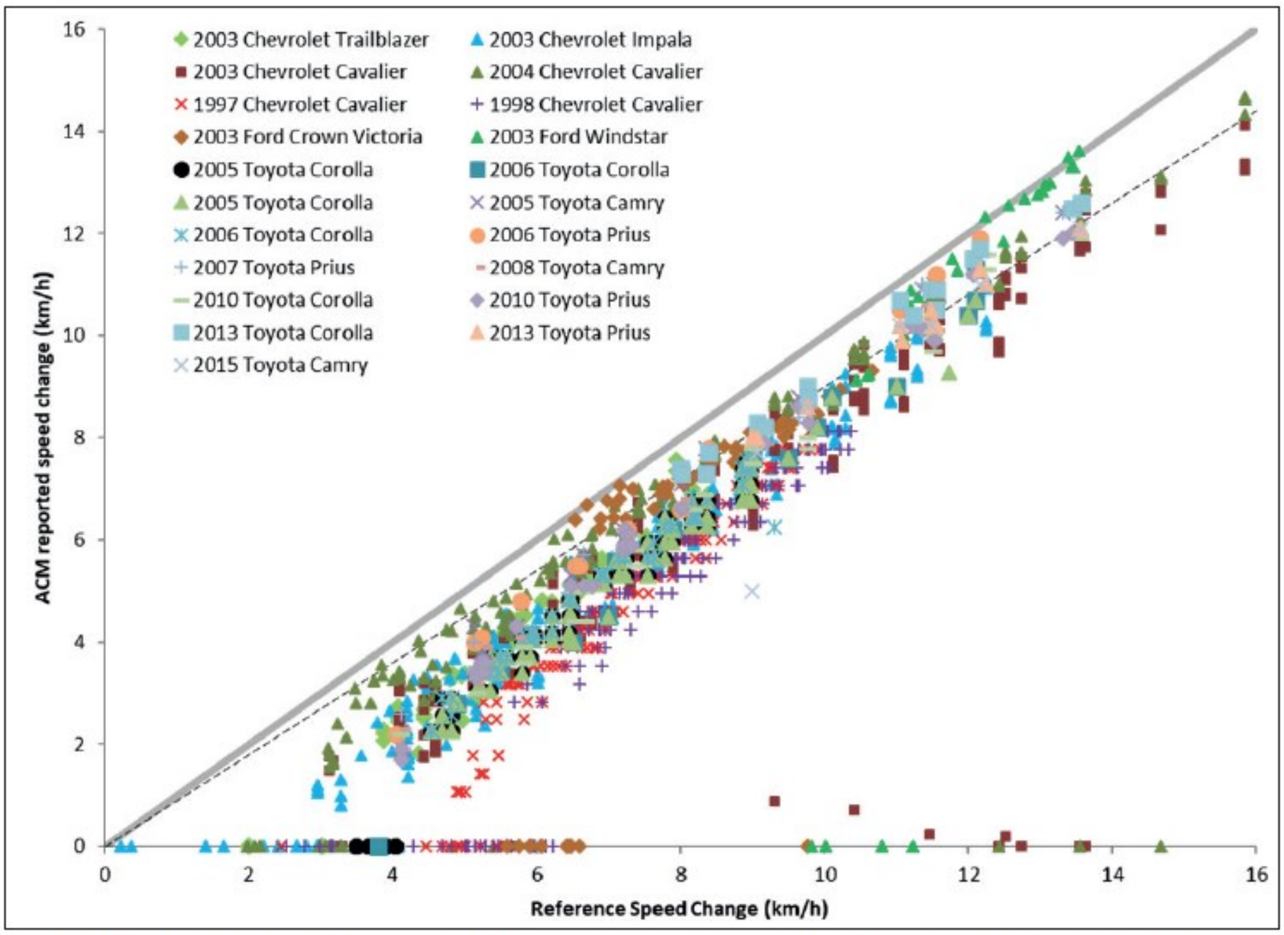

Figure 1: ACM reported speed change plotted against reference speed change (5th wheel or integrated accelerometer) from tests performed by MEA Forensic. The gray solid line represents unity, or the ACM reported speed change being equivalent to the reference speed change. The black dashed line represents a 10% error. The points on the x-axis represent crash tests in which no collision was recorded.

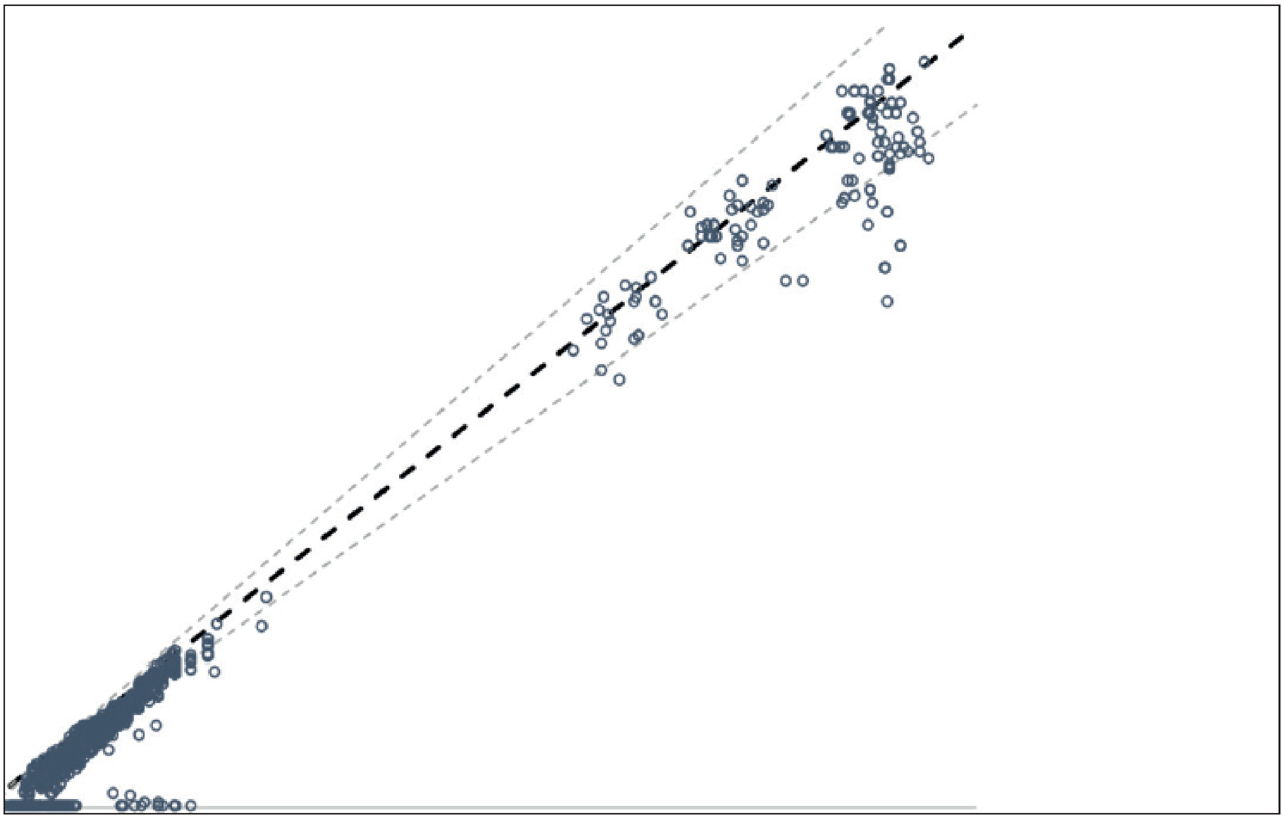

Figure 2: ACM reported speed change plotted against the reference speed change for the MEA Forensic, NHTSA and Transport Canada crash tests. The black dashed line represents unity. The gray dashed lines represent a 10% over and underestimate of the reference speed change.

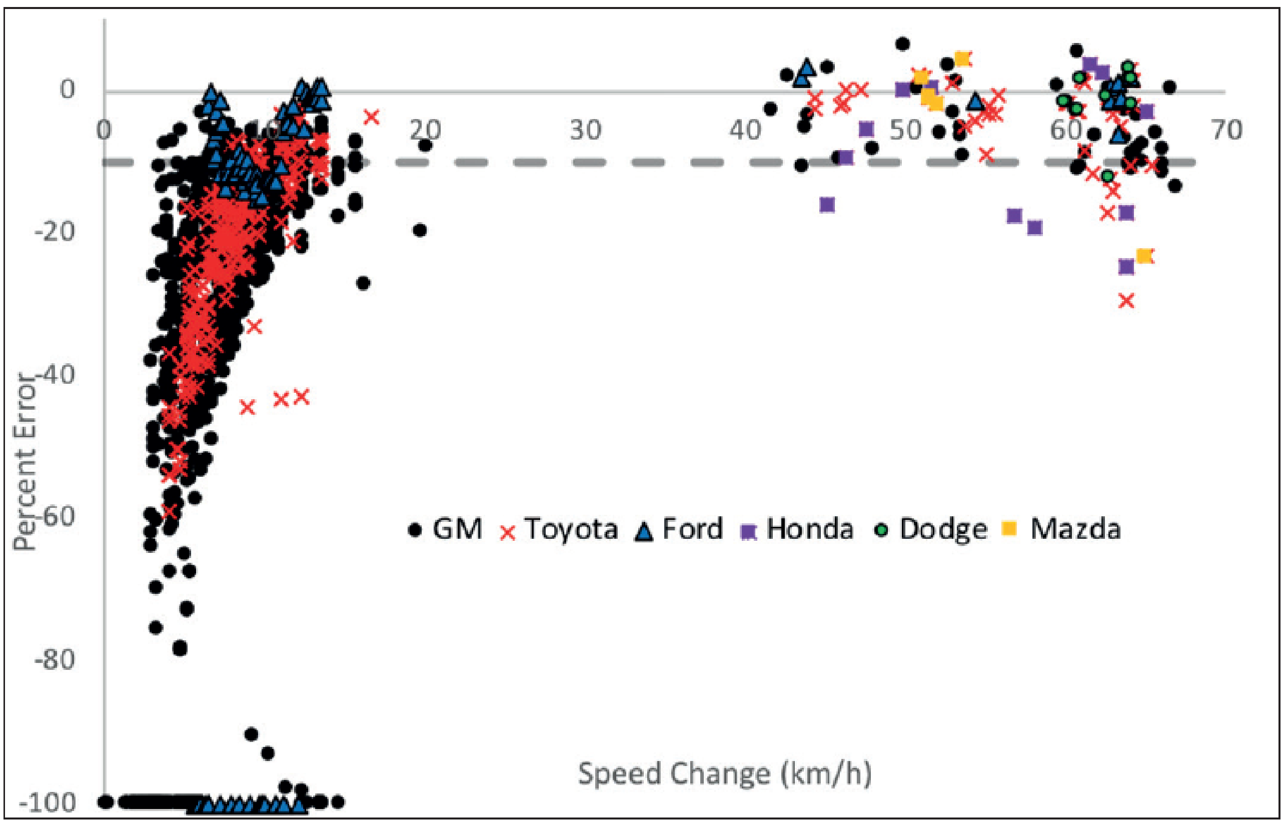

Figure 3: Percent error in the ACM reported speed change plotted against the reference speed change. The points at 100% error are tests in which no event was recorded. The gray line represents a 10% error.

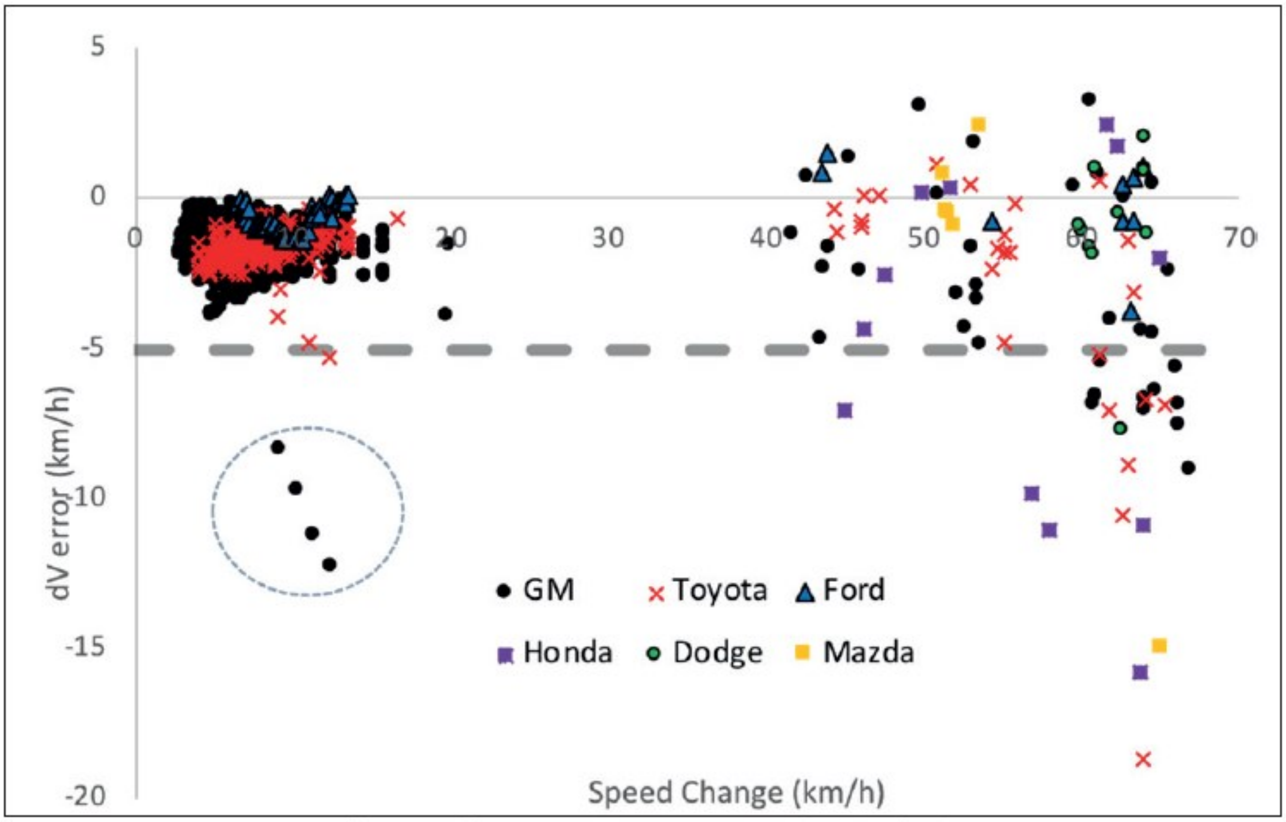

Figure 4: Speed change error plotted against the reference speed change of the crash test. The gray dashed line represents an underestimate of 5 km/h. The black data points (GM) circled in blue are 4 anomalous EDR reported speed changes from the same vehicle discussed by Wilkinson [3].

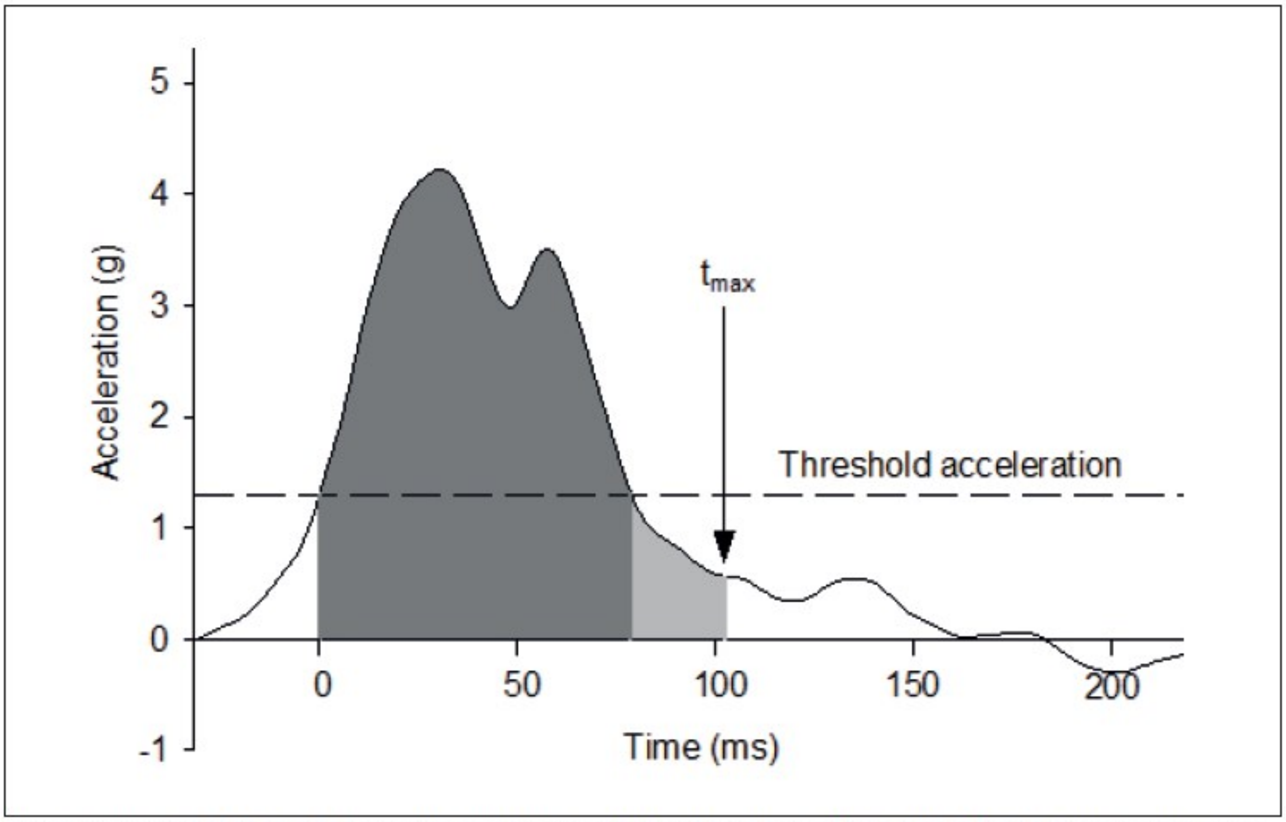

Figure 5: Schematic of two models used to calculate speed change from the accelerometer data. The dark shading corresponds to the integrated area of the threshold model. The light shaded area corresponds to the additional area included in the threshold time model. (Figure re-printed from Lawrence [1])

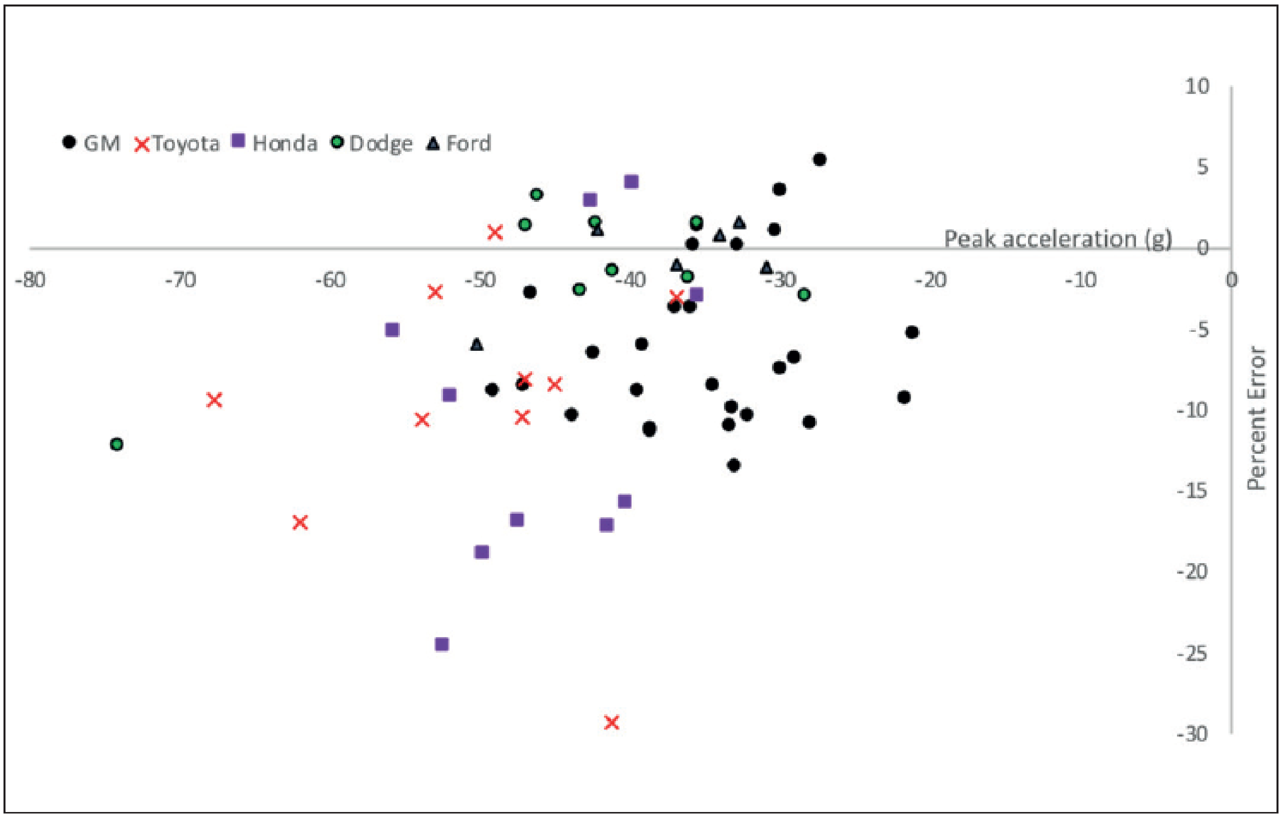

Figure 6: Percent error plotted against peak acceleration from the reference accelerometer filtered at 60 Hz.

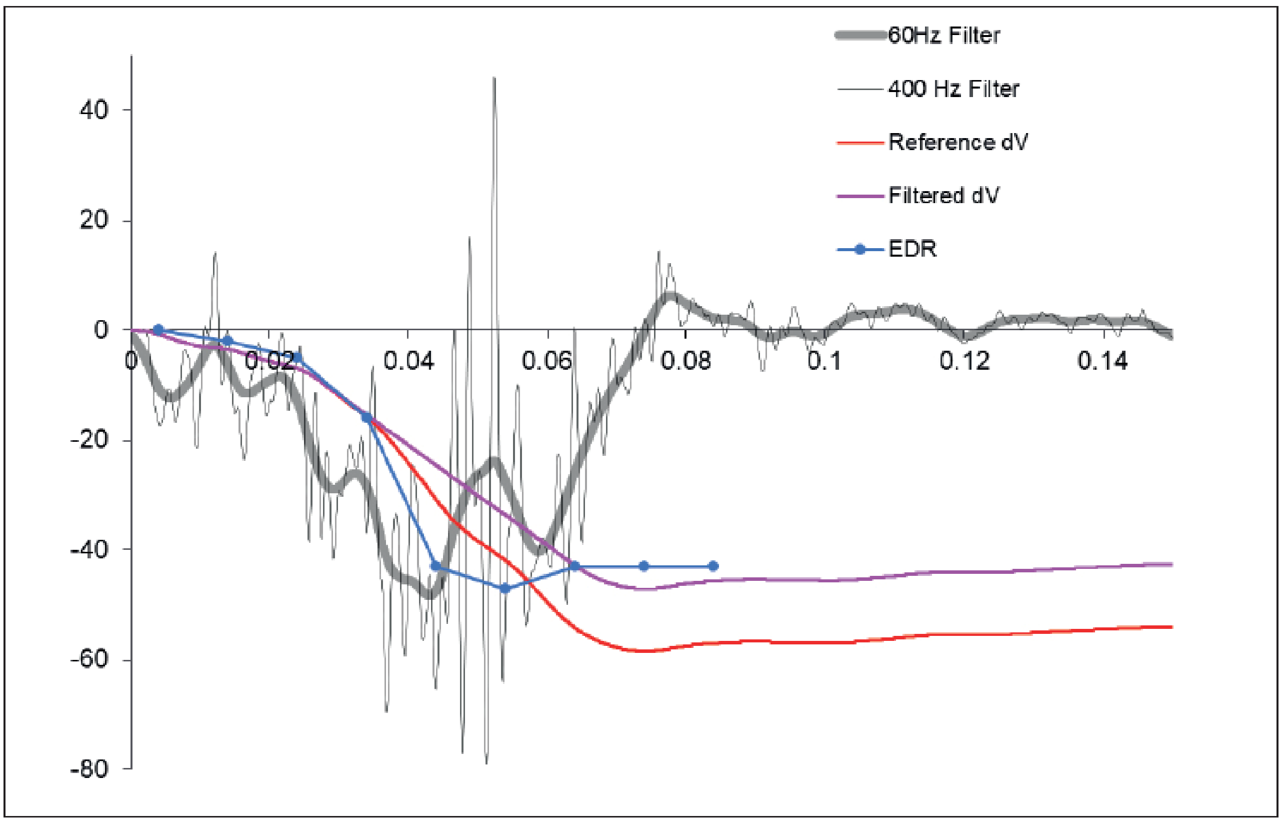

Figure 7: Comparison of EDR speed change, reference speed change and the speed changes predicted after clipping the reference accelerometer signal at -26g using the saturated model (km/h) for NHTSA test 9043 of a 2015 Honda Fit. The thick gray line shows the acceleration curve (in g) filtered at 60 Hz and the thinner gray line shows the acceleration pulse filtered at 400 Hz.

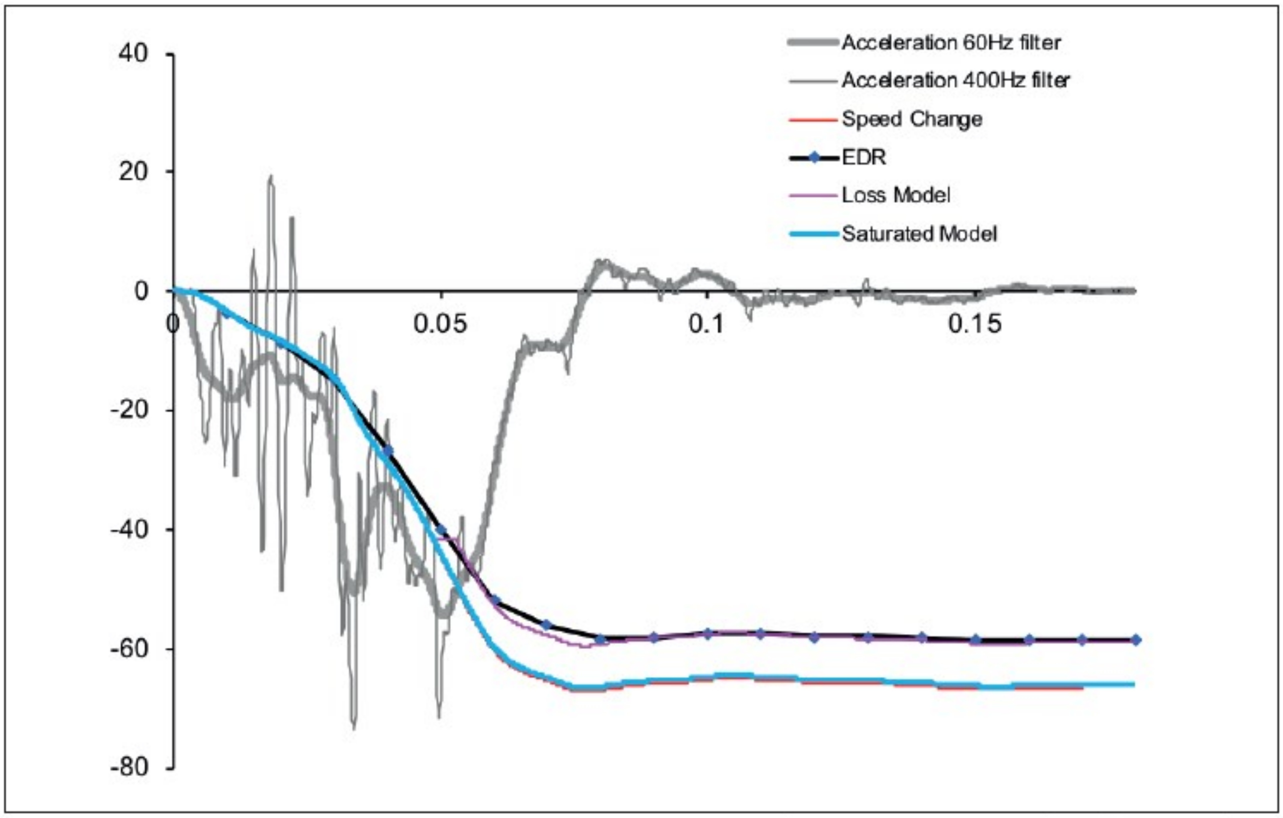

Figure 8: Comparison of EDR speed change, reference speed change and the speed changes predicted after clipping the reference accelerometer signal at -50g using both the saturated and loss models (km/h) for NHTSA test 7605 of a 2012 Toyota Yaris. The thick gray line shows the acceleration curve (in g) filtered at 60 Hz and the thinner gray line shows the acceleration pulse filtered at 400 Hz.

Figure 9: Pre (top) and Post(bottom) crash photographs of the right front footwell of a 2012 Toyota Sienna (NHTSA test #7615). The red arrow in the post-crash photograph illustrates the approximate location of the ACM. Based on the photographs, there was significant intrusion and deformation in the area of the ACM.

Table 2: *Summary of the NHTSA and Transport Canada crash tests used.*

NHTSA/ TC	MY	Make	Model	dV Test (km/h)	%err EDR	NHTSA/ TC	MY	Make	Model	dV Test (km/h)	%err EDR
3066	1998	Chevrolet	Malibu	53.6	-9.1	7587	2012	Chrysler	300	64.0	3.1
3085	1999	Chevrolet	Malibu	41.8	-2.9	7592	2012	Ram	1500	60.7	-2.7
3096	1999	Chevrolet	Cavalier	53.2	-3.2	7605	2012	Toyota	Yaris	65.4	-10.6
3112	1998	Chevrolet	Cavalier	45.3	2.9	7606	2012	Dodge	Charger	64.1	1.5
3177	1998	Chevrolet	Cavalier	42.7	1.6	7615	2012	Toyota	Sienna	63.8	-29.4
3178	1998	Chevrolet	Cavalier	44.1	-3.9	7618	2012	Lexus	ES350	63.3	-8.1
3180	1999	Chevrolet	Cavalier	53.4	-5.4	7619	2012	Honda	Civic	61.6	3.9
3851	2002	Chevrolet	Avalanche	62.8	0.1	7622	2012	Honda	CR-Z	63.7	-24.7
3952	2002	Buick	Rendezvous	66.6	0.1	7623	2012	Ford	F250	64.0	1.7
4134	2000	Ford	Taurus	54.3	-1.3	7624	2012	Ford	Expedition	62.7	-1.2
4198	2002	Saturn	Vue	65.7	-6.1	7625	2012	Ford	150	62.7	0.8
4238	2002	Cadillac	Deville	64.8	-7.6	7627	2012	Honda	Civic	65.0	-3.0
4244	2002	Chevrolet	Trailblazer	61.9	-6.5	7729	2012	Scion	iQ	65.1	-9.4
4445	2003	Chevrolet	Cavalier	66.2	-11.4	7732	2012	Honda	CR-V	63.9	-17.0
4453	2003	Chevrolet	Silverado	43.7	-10.9	7744	2012	Toyota	RAV 4	62.6	-16.9
4454	2003	Chevrolet	Tahoe	43.8	-5.4	7747	2012	Ram	2500	60.9	-3.1
4464	2003	Chevrolet	Avalanche	63.8	-7.0	7755	2012	Toyota	4Runner	61.2	1.0
4472	2003	Chevrolet	Silverado	66.9	-13.5	7851	2011	Chevrolet	Cruze	52.2	-6.1
4487	2003	Saturn	Ion	64.5	-3.7	7852	2011	Chevrolet	Cruze	53.4	-6.4
4549	2003	Chevrolet	Tahoe	64.8	-10.0	8789	2014	Honda	Accord	51.6	0.8
4567	2003	Chevrolet	Suburban	66.0	-8.6	8790	2014	Toyota	Camry	50.8	2.2
4702	2002	Saturn	Vue	53.4	0.9	8791	2014	Honda	Odyssey	45.1	-15.7
4714	2002	Saturn	Vue	52.8	3.4	8998	2014	Mazda	CX-5	51.2	1.6
4775	2004	Pontiac	Grand Prix	64.6	-3.7	8999	2014	Mazda	3	53.6	4.5
4899	2004	Cadillac	SRX	64.1	-9.0	9042	2014	Honda	Accord	49.8	0.4
4918	2004	GMC	Envoy XUV	60.9	-10.8	9043	2015	Honda	Fit	58.0	-19.0
4923	2004	Chevrolet	Colorado	64.1	-10.5	9476	2015	Chevrolet	Malibu	50.0	6.1
4984	2004	Saturn	Ion	46.0	-9.5	9477	2015	Cherolet	Malibu	59.6	0.7
4985	2005	Chevrolet	Equinox	66.2	-10.4	9478	2015	Ford	F 150	43.9	3.4
5523	2005	Toyota	Camry	46.2	0.3	9479	2015	Ford	F 150	43.5	1.9
7464	2012	Dodge	Avenger	61.1	1.5	9480	2015	Toyota	Highlander	44.3	-0.9
7467	2011	Buick	Lacrosse	48.0	-8.3	9481	2015	Toyota	Highlander	44.4	-2.5
7471	2012	Dodge	Journey	60.1	-1.8	9482	2015	Honda	Fit	56.9	-17.3
7475	2012	Ford	Mustang	63.4	-1.1	9499	2016	Mazda	CX-5	51.5	-1.0
7478	2012	Ford	Focus	63.3	1.1	9500	2016	Mazda	CX-5	51.4	-0.8
7482	2012	Chrysler	200	64.2	-1.9	9501	2016	Mazda	CX-5	51.9	-1.7
7488	2012	Chevrolet	Impala	64.1	-11.1	9727	2015	Chevrolet	Malibu	50.9	0.2
7494	2012	Chevrolet	Camaro	60.9	-11.3	10099	2017	Honda	Ridgeline	46.3	-9.3
7495	2012	Ford	Explorer	63.2	-5.9	10119	2017	Honda	Ridgeline	47.5	-5.3
7502	2012	Toyota	Tacoma	64.0	-10.5	10133	2017	Toyota	Corolla	55.8	-0.4
7505	2012	Fiat	500	62.7	-12.3	10154	2017	Nissan	Altima	53.7	-5.0
7509	2012	Chevrolet	Suburban	60.8	5.3	05-119	2005	Toyota	Camry	55.2	-3.2
7520	2012	Toyota	Camry	61.2	-8.4	05-203	2005	Toyota	Camry	62.9	-14.1
7521	2012	Cadillac	CTS	63.9	-3.0	09-243	2009	Toyota	Corolla	46.2	-1.7
7525	2012	Dodge	Durango	64.2	1.3	09-244	2009	Toyota	Corolla	55.1	-8.6
7527	2012	Ram	1500	60.0	-1.6	09-245	2009	Toyota	Corolla	63.4	-4.8
7531	2012	Cadillac	SRX	64.5	-8.6	10-211	2010	Toyota	Corolla	47.2	0.3
7564	2012	Chevrolet	Sonic	61.4	-8.9	10-149	2010	Toyota	Corolla	55.2	-2.3
7566	2012	Mazda	6	65.0	-23.1	09-220	2009	Toyota	Matrix	46.0	-2.1
7567	2012	Jeep	Liberty	62.5	-0.8	09-145	2009	Toyota	Matrix	54.8	-3.1
7577	2012	Volvo	S60	63.0	-3.1	09-219	2009	Toyota	Matrix	55.5	-3.2
7579	2012	Honda	Fit	62.3	2.8	09-262	2009	Toyota	Matrix XRS	54.3	-4.3
7582	2012	Chevrolet	Silverado	61.2	1.3	09-261	2009	Toyota	Matrix XRS	61.7	-11.5
7585	2012	Toyota	Tundra	63.2	-2.7	09-146	2009	Toyota	Venza	53.0	0.9

Probabilistic reasoning in the FCIN

Frances Senior
Head of the Forensic Collision Investigation Network

If you told me that smoking causes cancer, I could reasonably respond with the argument that my Auntie Peggy smoked all her adult life and never developed cancer, so smoking doesn't cause cancer. Would that make me right and you wrong? No, not at all, as we all know that a contributory cause of cancer is indeed smoking. The likelihood of developing cancer is known to be much higher in smokers than in non-smokers, so smoking is a contributory factor, whether or not developing cancer is the outcome.

So why am I talking about cancer? The above is an example of causal reasoning and is totally applicable to the forensic sciences and ergo, Forensic Collision Investigation. An FCI's personal experiences do not invalidate statistical generalisations, particularly as they are by virtue probabilistic. Now I am no expert in statistics, as any member of my team will tell you, but I do understand the subject of probabilistic reasoning.

As a more relevant example – in this instance I shall say that the primary causation factor of hit and run pedestrian collisions is the pedestrian wearing dark clothing.

Then; if you as an FCI have attended a dozen hit and run pedestrian collisions and the investigation determined that a combination of drugs and alcohol were present in each one of those collisions, but the pedestrian in each one was wearing light coloured clothing, you could reasonably expect to find drugs or alcohol and light-coloured clothing in the next hit and run pedestrian collision you attend. But, your lived experience of your dozen previous collisions does not falsify the statistical generalisation that exists in this type of collision.

Lived experiences, whilst inherently valuable in many areas of life, science and cognitive function, are not the best grounding for statistical reasoning. Why is that? Well, with every person being unique, it makes sense that every experience is also unique. So, what does that tell us as forensic practitioners? It tells us that our lived experiences are useful tools for the investigation at hand, but that any output is likely to be skewed with the practitioner's cognitive bias, so needs to be balanced with well-developed tools for the analysis, evaluation and interpretation of evidence in order to safeguard against personal bias.

So how does this link in with the work of the FCIN? Forensic scientists in many disciplines are expected to evaluate evidence, providing often a numerical judgement about the value of the evidence in the relevant context. This can include the likelihood ratio in which the interest lies in the probability of the evidence against two opposing propositions – a prosecution and defence, or alternative proposition.

As we have carried out reviews nationally of the scene notebooks, forms or digital solutions, we identified a distinct gap in the formulation of hypothesis, which was unsurprising as this has also been encountered in the other Police delivered forensic disciplines prior to accreditation. It may surprise you to know that fingerprint experts who have historically identified unique factors in fingerprints prior to matching fingerprint A to donor A, because of accreditation, must now demonstrate the full rationale for any matches and that alternative hypothesis are also considered.

Although FCIs can extract "accurate" information from a single piece of evidence, such as CCTV footage of a crash, establishing (or denying) the relationships between that piece of evidence and say, for example, the telematics of the vehicle or the in-car dash cam footage is still a challenging task.

How those conflicting evidence types interact with each other and add to, or detract from, the conclusions are in other forensic sciences dealt with by different models for interpretation and presentation of evidence.

The different models of probabilistic reasoning, Bayesian Inferential Reasoning and Likelihood ratios, are very well researched and complex in their own right, I would encourage practitioners to undertake further reading on the subjects to broaden your knowledge as over the coming months and years, through the rigorous process of accreditation and regulation, they become much more important to the science of forensic collision investigation.

The FCIN, on behalf of all 43 Police Forces in England and Wales, are currently designing and applying the logic that underpins much of this theory to the 'outputs' we are delivering.

What are we doing # 1?

We have created a national scene note template, a very robust, detailed and methodical structure to the scene note capture that ensures that hypotheses are captured at the relevant points of the examination and re-evaluated as new evidence is presented to the investigator.

What benefits will this deliver?

This will provide national conformity of practice and evidence capture at every scene in every part of England and Wales. It will ensure the data collected can be recorded and analysed accurately and have the end result of truly understanding themes, trends, causations and issues. It will provide stakeholders with rich data that can underpin national casualty reduction strategy and reduce risk on our roads. It will reduce margins for error or omission.

What are we doing # 2?

We are carrying out detailed experimental design and statistical review of method validation tests, ensuring that we carry out sufficient experiments to capture the variables in a statistically valid method and then evaluating the findings using the correct statistical model as required.

What benefits will this deliver?

This will ensure the 'science' that FCIs are delivering within the network is sound, statistically accurate and reliable.

What are we doing # 3?

We are designing a robust and thorough quality assurance reporting process, whereby FCI reports will follow the same process through a series of checks and balances, not within their own unit or Force, but nationally and 'blindly' without previous knowledge of the case in question. Within this process there will be strategy meetings with 'customers' and thoroughly documented rationale and hypothesis – in exactly the same manner as you would expect to find in a murder or other serious crime enquiry.

What benefits will this deliver?

This will raise standards across the network and remove possibility for bias. It will also provide network wide standardisation and learning opportunities, reduction of dispute between customer and forensic provider and safeguards within the system to ensure accuracy and the highest standards of quality possible.

What are we doing # 4?

We will be competency testing all FCIs within the network on an annual basis, against set areas within the scope of accredited activities. As the scope expands, so will the competency testing requirements.

What benefits will this deliver?

This will create a register of authorised practitioners, along with the scope of their competency. It will provide the practitioner with knowledge of any areas requiring development and a personal development plan to enable them to be re-tested. This will create a level 'playing field' of FCIs across the network and assurances to the customers/CJS as to the expertise of the FCI.

These four examples are just a few of the outputs of what is an exciting, if not very challenging, journey for Police delivered forensic collision investigation. FCI as a forensic science, whilst not 'new', is certainly on a steep trajectory of development and professionalisation previously beyond reach.

So if you told me now that forensic collision investigation within Policing was fine as it is, then pointed to any of the hugely experienced and competent practitioners out there as the evidence to back that statement up, I would have to say with a strong likelihood ratio that yes, FCI as a science WAS fine as it was, but moving forwards as an accredited and regulated forensic science within Policing, there is much that can be done to professionalise it and move it forwards and that we will be providing all FCIs within the FCIN with the knowledge, skills and tools required to enable them to deliver the very best evidence possible.

Whilst we have yet to venture into probabilistic reasoning, Bayesian inferential reasoning or likelihood ratios as business as usual, it is certainly just around the corner.

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FORENSIC COLLISION INVESTIGATION NETWORK

Newsletter

David G Davies
Executive Director, PACTS

PARLIAMENTARY ADVISORY COUNCIL FOR TRANSPORT SAFETY

PACTS is a transport safety body which promotes evidence-based safety policies to parliamentarians, government and key stakeholders. It was founded 40 years ago by a coalition of experts, campaigners and parliamentarians who succeeded in making seat belt wearing compulsory. We try to cover a wide range of issues, including air and rail safety. We focus mainly on roads because that's where most people are killed or injured. Our involvement in air and rail safety gives us insights into how safety in managed in these sectors, including how accident Investigation is conducted.

Over the past five years, PACTS has been calling for improved in-depth road accident investigation and learning from it. The Stats19 forms completed by the officer at the scene of a collision are useful. Stat19 provides the bedrock of UK road safety data and invaluable information on the quantity of collisions and casualties, and many associated and contributory factors. But the officer has only a short time to record information, inevitably based sometimes on impressions (not detailed examination). It usually focuses on user behavioural aspects, such as insufficient attention or excessive speed. The officers usually don't have the time or training to look into things like road layout or vehicle design and the full range of safe system factors. Critical safety factors such as seatbelt wearing are often substantially under recorded, or inaccurate. The new CRASH reporting system is helping to improve accuracy and completeness but it will always lack in-depth examination.

In-depth investigation usually does take place into fatal and the most serious injury collisions by the police and others. However, learning from these investigations is not shared. Indeed, it is difficult to get even basic information about any aspect of them as the remit for the police is prosecution, not learning.

The DfT has funded in-depth studies (On-the-Spot, RAIDS etc) by TRL and Loughborough University, mainly to identify potential improvements in vehicle design safety. Bodies such as Highways England and Transport for London have commissioned their own from time to time. These need to be made more mainstream.

The Law Commission is also suggesting that a new body be established to investigate collisions involving autonomous vehicles which will involve many new technical and legal challenges.

It is sometimes hard to demonstrate the effectiveness of an organisation such as PACTS. We don't get Acts of Parliament amended every day! But I genuinely think that collision investigation is one issue where we have had real impact. Five years ago, I had a conversation with a senior DfT road safety official who said that "everyone" in the department was against having some sort of accident investigation branch for roads. In response to a Parliamentary Question, the Minister replied that the police carried out accident investigation and there was no need for another body or process.

But that has changed. Following the DfT's 2019 Road Safety Statement, the DfT has supported the Road Collison Investigation Project run by the RAC Foundation with input from Highways England, Transport for London and others. It will report next year on whether there is business case for setting up the equivalent of a road collision investigation branch. Given that the economic value of preventing one fatality is approaching £2 million, if the new body led to a reduction in only a few fatalities, it would have an eye-popping rate of return. How it would relate to existing collision investigators would need to be worked out but I'm sure it would want to draw on their expertise and not replace it.

On broader matters, PACTS Is very encouraged by the smoke signals rising from Great Minster House about a new, broadly-based and much more ambitious road safety strategy for the coming years.

PACTS has a small staff and we depend very much on the input of our 100+ members. They are often our eyers and ears, experts working at the coal face. They contribute to our in our meetings, conferences and research. We very much value the input we have had over the years from ITAI. We share many common objectives and we really value their expert input. Long may it continue.

David G Davies

Executive Director,

Parliamentary Advisory Council for Transport Safety

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'Impact' is published 3 times each year (April, September, December) and is circulated to all members of the Institute in the UK and overseas. In addition, there are many non-member subscribers (also in the UK and overseas), who receive the publication.

The journal reaches specialist police officers, researchers, private consultants, engineers and other professionals involved in collision investigation.

'Impact' is now in its 29th year ! Over that period, advertisements placed in the journal have proved highly effective in alerting its readers to -

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Electric Scooter Specifications and Test Results

Wade Bartlett and Victor Craig

Background

Small stand-on two wheel vehicles commonly called "scooters" have been around since 1915. They were initially human-powered, but within a few months of their introduction scooters powered by small gasoline engines made their appearance. Around the year 2000, electric scooters surpassed gas engine scooters in popularity.[1]

Electric scooters, often called e-scooters, have since become a phenomenon in numerous cities and college towns, where people look to avoid rising traffic congestion by replacing short car rides with bike and scooter trips. Ride share e-scooters have become wildly popular, too. In 2018, 38.5 million trips were taken on shared scooters across dozens of US cities, according to the National Association of City Transportation Officials.[2] Figures 1, 2 and 3 present images of typical electric scooters.

Naturally, higher usage means a higher number of accidents, some of them serious. The Centers for Disease Control (CDC) partnered with the Public Health and Transportation departments in Austin, Texas, to analyze 936,110 e-scooter trips between Sept. 5, 2018 and Nov. 30, 2018. There were 271 people involved in some type of e-scooter incident that resulted in an injury. The CDC was able to confirm 130 such cases, amounting to an injury rate of 14.3 per 100,000 trips. Nearly half of those hurt in e-scooter crashes sustained head injuries, 15 percent of which were traumatic. The CDC said less than one percent of the riders it studied wore helmets.[3]

And of course, accidents involving vehicles and injuries lead to involvement of law enforcement and civilian traffic collision reconstructionists.

Obtaining and Analyzing the Data

The lead author happened across a website titled Electric Scooter Guide, (ESG) that had actual test data for a great many small electric scooters, as well as some manufacturer specifications (in two separate pages, of course). An Excel file was created, and analysis of their data began. This article will outline the process used to get and evaluate the data, as

Figure 1. GoTrax XR Ultra (Source: https://gotrax.com/)

Figure 2. Apollo City (Source: https://apolloscooters.co/)

Figure 3. Dualtron Thunder (Source: https://www.minimotors-nyc.com/

well as report the results with regards to acceleration and braking rates. The Excel file created can be found in the Reference Library on the NAPARS website.

The manufacturer specifications can be found in Reference 5. Information in this spreadsheet included weight (pounds), motor power (Watts), top speed (mph), battery size (Watt-hours), and brake style (disc, drum, other), and more, as well as links to the manufacturer or a sales website. The table was copied from the browser, and pasted into WORD first, then copied again and pasted "as text" into an EXCEL spreadsheet. This created a database with 123 models from 33 manufacturers. This first-WORD-then-EXCEL process seems odd, but the two programs parse tables differently, and this worked very well in this case to create a clean and organized table with no anomalies that required special attention to fix.

ESG's test results were on a different page.[6] Using the same cut-paste-to-Wordthen- Excel sequence generated a clean spreadsheet of their performance data. This included datasets of varying completeness for 57 models from 27 different manufacturers. Many included time to accelerate to 15, 20, 25 mph, a top speed, and a distance to brake to a stop from 15 mph. This information was placed in the spreadsheet as well.

The lead author combined the two datasets and collated each line item to match the manufacturer data to the test results for specific models. That tab then copied into a fourth tab for analysis. All the partial datasets were deleted and renamed that tab "COMBINED – Just full datasets".

Table 1 lists most of the data found in this file.

Acceleration Tests

ESG reported that they tested all the scooters as follows: On level ground, batteries fully charged, set to highest output (where it was an option), and with a 165-pound rider. Figure 4 shows the average acceleration as a function of motor power, for the 49 tests to 15mph and the 11 tests to 30 mph. For this analysis, the very few high-powered scooters with motor power ratings above 2500W were excluded.

The high R2 value indicates that the variation in acceleration is well correlated with motor power. This seems likely to be a causal relationship, but that nuance is not important to this discussion. The same "goodness of fit" R2 term for the 30 mph dataset (with only 11 tests) is under 0.5, and is not shown here.

As expected, the average acceleration drops as speeds go up. This chart shows the drop is approximately 0.007g per added mile per hour of speed up to 15 mph. The variation at each wattage is likely a result of driveline specifications (gear teeth, motor efficiency, etc.), as well as standard testing noise.

One could also plot the time-to-speed for all the tested units as a function of motor power, as shown in Figure 5. Following a similar procedure to the one outlined in previous papers [7,8], one can find the best-fit curves for the data at each speed (15, 20, 25, and 30 mph [not shown here]), and use those relationships to produce reasonably accurate time-distance predictions.

Including the weight of the scooter in the equation, and adding the 165-pound rider does not produce any better correlation than simply using the motor power. It will not be considered further.

Braking

The tested scooters included 4 different types of braking system. Table 2 shows the overall result for each type. Figure 6 shows the average deceleration as a function of the Manufacturer's Suggested Retail Price (MSRP). Typical maximum braking value was 0.55g, a lower value than what is typically possible for street motorcycles.[9], but nearly yhe same as is achieved by average riders.[10]

TABLE 1. Electric Scooter Specifications and Test Results

Make	Model	Weight (lb)	Max. Weight (lb)	Motor (W)	Top Speed (mph)	Acceleration (g's)			Brakes	Stopping (15 to 0)	
						0 to 15 mph	0 to 20 mph	0 to 25 mph		Dist. (ft)	Decel. (g's)
Apollo	City	40	260	600	25	0.159	0.132	0.096	Disc	12	-0.625
Apollo	Explore	53	265	1000	31	0.195	0.160	0.119	Disc	11	-0.682
Apollo	Light	37	220	350	22	0.139	0.111		Drum	17	-0.441
Apollo	Pro (60V)	77	330	2000	42	0.402	0.350	0.300	Disc	8	-0.938
Apollo	Pro Ludicrous (60V)	77	330	2400	44	0.402	0.396	0.367	Disc	9	-0.833
Boosted	Rev	46	250	1500	24	0.253	0.202		Disc	17	-0.441
EMOVE	Cruiser	52	352	600	28	0.201	0.157	0.104	Disc	11	-0.682
EMOVE	Touring	40	308	500	25	0.175	0.120		Drum	16	-0.469
EVOLV	Tour XL Plus	51	264	600	28	0.152	0.127	0.093	Disc	13	-0.577
Fiido	Q1S	44	330	250	15	0.102			Disc	13	-0.577
Fluid Freeride	CityRider	28	220	300	18	0.056			Drum	27	-0.278
Fluid Freeride	Horizon (13 Ah)	42	264	500	25	0.145	0.117		Drum	23	-0.326
Glion	Dolly	29	255	250	15	0.073			Electronic		
GoTrax	G4	36	220	350	20	0.108	0.081		Disc	21	-0.357
GoTrax	GXL Commuter v2	26	220	250	16	0.068			Disc	16	-0.469
GoTrax	Xr	26	220	250	16	0.083			Disc	14	-0.536
GoTrax	Xr Elite	32	220	300	16	0.090			Disc	14	-0.536
GoTrax	Xr Ultra	26	220	300	16	0.088			Disc	14	-0.536
Hiboy	MAX V2	35	265	350	19	0.075			Disc	17	-0.441
Hiboy	S2	29	265	350	15	0.110			Disc	14	-0.536
InMotion	L9	53	330	1000	19	0.163			Disc	17	-0.441
Inokim	Light 2	30	220	350	21	0.120	0.052		Drum	11	-0.682
Inokim	OX	57	264	800	28	0.129	0.117	0.088	Disc	11	-0.682
Inokim	Quick 4 Super	47	220	600	25	0.145	0.105		Drum	12	-0.625
Kaabo	Mantis	61	264	2000	40	0.273	0.234	0.219	Disc	11	-0.682
Kaabo	Mantis 8	50	265	800	28	0.139	0.111	0.076	Disc	10	-0.750
Kaabo	Mantis Pro	65	264	2000	40	0.342	0.325	0.278	Disc	10	-0.750
Kaabo	Skywalker 10S	56	264	1200	36	0.185	0.163	0.125	Disc	9	-0.833
Kaabo	Wolf Warrior 11	101	330	2400	50	0.360	0.396	0.292	Disc	11	-0.682
Levy	Levy	27	230	350	18	0.112			Disc	21	-0.357
Mercane	WideWheel (Dual)	44	220	1000	25	0.236	0.190	0.093	Disc	21	-0.357
Mercane	WideWheel Pro	54	220	1000	26	0.214	0.175	0.136	Disc	12	-0.625
Minimotors	Dualtron Eagle Pro	66	265	1800	40	0.253	0.240	0.187	Disc	11	-0.682
Minimotors	Dualtron Spider	47	220	1300	37	0.263			Disc		
Minimotors	Dualtron III	79	264	1600	40				Disc		
Minimotors	Dualtron Thunder	95	330	5400	50	0.325			Disc	20	-0.375
Minimotors	Dualtron X	145	300	6720	55	0.311	0.304	0.285	Disc	17	-0.441
Qiewa	QPower	81	661	3200	55	0.380	0.337	0.308	Disc	9	-0.833
Segway	Ninebot ES2	29	220	300	16	0.096			Foot	17	-0.441
Segway	Ninebot Max	42	220	350	19	0.127			Drum	17	-0.441
Splach	Turbo	45	264	600	28	0.159	0.118		Drum	15	-0.500
Swagtron	Swagger 5	26	320	250	18				Disc		
TurboAnt	X7 Pro	33	275	350	20	0.075			Disc	17	-0.441
Unagi	Model One (E500)	26	275	500	20	0.155			Electronic	16	-0.469
Uscooters	Booster GT	29	275	700	25	0.127	0.105		Drum	15	-0.500
Uscooters	Booster Sport	24	279	500	25	0.108	0.089		Foot	18	-0.417
UScooters	Booster V	24	279	500	25	0.120	0.086		Foot	18	-0.417
WEPED	GT 50E	77	220	3600	45	0.311			Drum	10	-0.750
Xiaomi	Mi M365	26	220	250	16	0.108			Disc	16	-0.469
Xiaomi	M365 Pro	31	220	300	16	0.129			Disc	15	-0.500
Zero	8	40	220	500	22	0.139	0.108		Drum	23	-0.326
Zero	8X	72	265	1600	33	0.325	0.253	0.207	Disc	11	-0.682
Zero	9	40	220	600	24	0.163	0.128	0.097	Disc	10	-0.750
Zero	10X (18 Ah)	80	330	2000	35	0.244	0.212	0.184	Disc	16	-0.469
Zero	10X (23 Ah)	80	330	2000	40	0.273	0.253	0.223	Disc	12	-0.625

Top Speed/Power

Top speed for the vehicles listed in Table 1 ranged from 15 to 55 mph [24 - 88 km/h]. Motor power ranged from 250 to 6720 watts.

Motor power was found to be the best predictor of top speed. That relationship is shown in Figure 7.

Application

With the increasing usage of e-scooters on streets and sidewalks throughout the world comes an inevitable increase in the number of crashes and injuries associated with these vehicles.

Acceleration from a stop and braking accelerations achievable by dozens of small electric scooters, as listed by ESG, has been collated and analyzed. Any crash analyst handling a crash involving one of these new modes of transport will hopefully find this information useful.

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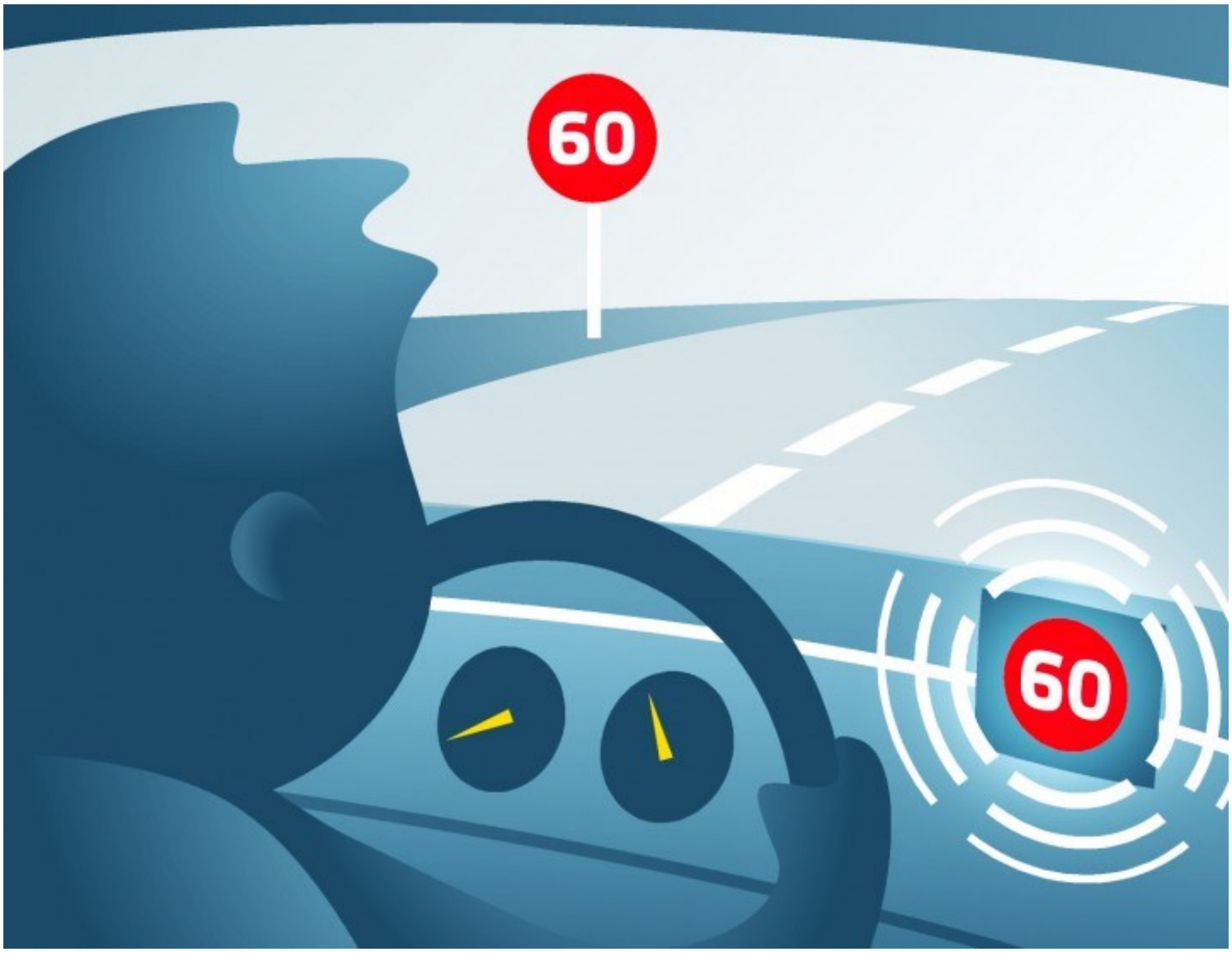
Intelligent Speed Assistance set for launch on all new EU vehicle types from 2022 - ETSC

31st May 2021



ETSC has welcomed endorsement by EU Member States of technical standards for Intelligent Speed Assistance (ISA), paving the way for the technology to be installed on all new models of vehicle sold in the European Union from next year. ETSC is calling on vehicle manufacturers to go beyond the minimum requirements of the legislation to maximise the huge potential safety benefits of the technology.

By next year, the European Union will have, by far, the most stringent vehicle safety standards in the world with systems including Advanced Emergency Braking (AEB), Emergency Lane Keeping Assist (ELKS), drowsiness and distraction recognition and Intelligent Speed Assistance (ISA) all mandatory. By 2024 every new car sold in the EU will need to be fitted with these technologies.

Although final agreement on the EU's new vehicle safety law, known as the "general safety regulation" was reached in 2019, detailed technical requirements for the various required systems are only being finalised now following almost a year of technical discussions.

In a meeting earlier this month, representatives of EU Member States signalled their informal approval for draft technical specifications for ISA that will be formally adopted in June.

The requirements allow for several different types of ISA system to be fitted. By law, every type of system must be overridable, and allow the driver to switch the system off for the duration of the current journey.

The most effective and appreciated systems, already available since 2015 on several vehicles, assist drivers by cutting engine power once the legal speed limit has been reached. The driver can override the system by pushing further down on the accelerator pedal. Systems that intervene in this way, could reduce road deaths by 20%.

However, following strong and sustained industry pressure, the EU is also allowing a system to be fitted for which no research is available and which is expected to be much less effective. The most basic system allowed simply features an audible warning that starts a few moments after the vehicle exceeds the speed limit and continues to sound for a maximum of five seconds. ETSC says research shows audible warnings are annoying to drivers, and therefore more likely to be switched off. A system that is deactivated has no safety benefit.

Antonio Avenoso, Executive Director of ETSC commented:

"More than twenty years after this technology was first trialled, it is great to see Intelligent Speed Assistance finally coming to all new vehicles in the EU. It is a big step forward for road safety.

"However, we are disappointed that carmakers are being given the option to install an unproven system that may have little safety benefit. We sincerely hope that carmakers will go beyond the minimum specifications and take full advantage of the life-saving potential of speed assistance technology. It saves lives, prevents serious injuries and saves fuel and emissions."

In a positive development, the draft requirements state that carmakers will have to report aggregate, anonymous data on how ISA systems are being used, and if they are being switched off by drivers. Two years after the legislation comes into force, it should be possible to see, based on real-world data, which systems are most effective. That will be a good opportunity to learn and react to improve the technology in the future.

ETSC
European Transport Safety Council

WREX 2023

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The next World Reconstruction Exposition, WREX 2023, will be held on April 17 – 21, 2023 at the Rosen Shingle Creek Hotel in Orlando, Florida. WREX 2016 was the largest crash conference ever hosted and many attendees said that it was the best they had ever attended. WREX 2023 is expected to be larger and even better than WREX 2016.

WREX 2023 will be hosted by a large group of international associations. Representatives from 24 groups are hard at work planning for, and refining, the next event. WREX 2023 will feature many of the top international speakers in the ever-expanding field of collision reconstruction. Crash Test Day at WREX 2023 will utilize multiple crash test teams to provide numerous high speed crash tests with minimal down time. The new off-site crash test location will facilitate easy access between staged collision events and provide for a better attendee experience. The Interactive Field-Testing Day (a.k.a. "Reconstruction Midway") at WREX 2023 will be held at a larger venue on site at the host hotel to accommodate even more exhibitors. High quality sit-down lunches will be served each day of the conference and are included as a part of your event registration fee. For those intent on getting the most bang for their training buck, evening presentations, including poster presentations of select collision reconstruction topics, will be available at WREX 2023.

The WREX 2023 planning staff can do a better job coordinating this event with your cooperation. The staff asks you to visit the conference website - www.wrex.org and add your name to the list of attendees ASAP. There is no cost to "pre-register" and no penalty for removing your name. An approxi-mate count of conference attendees will help the staff develop the best possible plan for the event. As a bonus for helping the staff by "pre-registering", two of the "pre-registered" attendees, whose names have been added to the list by September 30, 2021, will receive free admission to WREX 2023. Please help us to make this the best conference you have ever attended. Remember the attend-ee room block at the host hotel sold out in 2016. The WREX 2023 planning staff encourages you to reserve your hotel room ASAP to ensure your ability to stay on site while attending this sure-to-be spectacular event.

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