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A 50-DRIVER NATURALISTIC BRAKING STUDY: OVERVIEW AND FIRST RESULTS

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Abstract: Considering the importance of vehicle brake systems, it is surprising how little is known about the way that people operate them. Previous ergonomic studies have attempted to define the maximum acceptable resistance to depression in the pedal (Diffrient, Tilley, & Harman, 1993; Eaton & Dittmeier, 1970). Accordingly, they focussed on the responses of weak (5 percentile muscle strength) female drivers and little is known about the full range of braking response. A re-examination of this basic control mechanism is necessitated by the evolution of vehicle systems. The present paper offers an overview of a study measuring driver “pedipulation” in a naturalistic environment. Fifty-eight fully-licensed drivers drove a car for a day. The types of trip analysed included commuting to work, shopping, and picking up children from school. Measures taken included throttle pedal angle, brake pedal pressure, and clutch pedal pressure. The foot well was constantly video recorded during each trip. Main results are presented and comparisons with earlier studies are discussed.

Introduction

The safe driving of any road vehicle is achieved through successful control of its longitudinal and lateral dynamics. In practice, longitudinal control is speed control and this is carried out via operation of the pedals (throttle, brake and clutch) and the gear stick (where manual transmission applies). As movement and speed define whether two vehicles may collide and the size of the impact, brake operation is of unique importance in safe driving. According to accident data, braking is the most common road user reaction (when there is any) during the course of an accident (Gkikas, Hill, & Richardson, 2008).

Previous studies

Considering the above, it is surprising how quickly research moved from studies about the actual operation of the brake pedals (Eaton & Dittmeier, 1970) to studies of braking in relation to car-following/time to collision (TTC) and Adaptive Cruise Control (ACC) specification (Abe & Richardson, 2005; Chung & Yi, 2007; Dingus et al., 1997; Lin, Hwang, Su, & Chen, 2008; McCall & Trivedi, 2007; Van Der Horst, 1990; Van Winsum & Heino, 1996; Van Winsum, 1998) In parallel, driver braking has been used as a measurement of distraction in related studies (Harbluk, Noy, Trbovich, & Eizenman, 2007; Morita, Mashiko, & Okada; Sato & Akamatsu, 2007). The increased popularity and acceptance of multi-level models for the driving task (Lee, 2006; Michon, 1993; Summala, 1996) and the aggregated complexity induced by the introduction of new technologies in the car could partially explain this trend, however not completely. In contrast it could be argued that nearly 40 odd years

after Eaton's study on braking capabilities of drivers, it is time for an update on a task that could have changed a lot or not at all. The present paper presents results from an exploratory study of "naturalistic" driver braking.

Method

In order to explore 'normal' braking behaviour, 58 drivers drove an instrumented vehicle while completing various daytime trips. Trips included (but were not limited to) driving between home and work, driving children to and from school, shopping related trips etc.

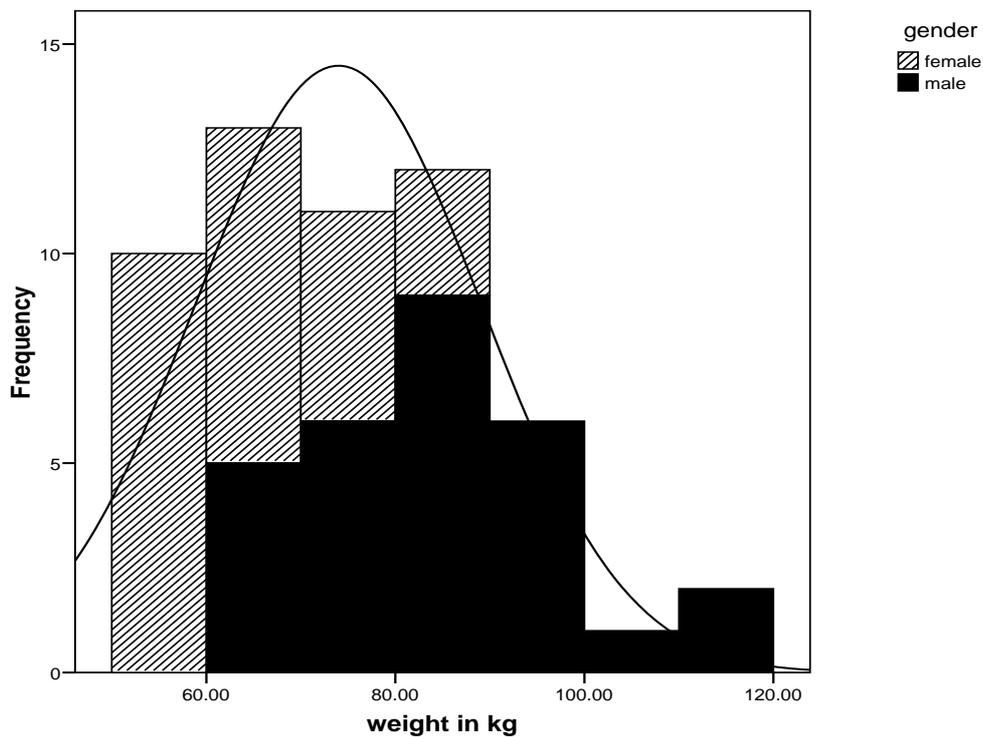


Figure 1: Stacked histogram of male/female participants' weight

Sample

58 fully licensed drivers with less than 6 points on their license took part in the study. Most of them were associated with Loughborough University or other local businesses. They ranged between 23 and 84 years in age (Mean: 35.76), between 1 and 48 years of driving experience (Mean: 16.37), between 1000 and 30,000 yearly mileage (Mean: 9733.33), between 152cm and 193cm in height (Mean: 171.48cm), and between 50 and 115 kilograms in weight (Mean: 73.91). 30 were male and 28 were female. Figures 1 and 2 show the distribution in height and weight of the participants (stacked male-female groups).

Apparatus: the instrumented vehicle

For the purpose of the study, a T registration plate Ford Fiesta was instrumented with sensors on the pedals and a camera in the foot-well. Tekscan Flexiforce® sensors were installed on the surface of the brake pedal and the clutch. A potentiometer was installed at the centre of rotation of the throttle pedal. Flexiforce® sensors were calibrated and conditioned according to Tekscan guidelines. U12 Labjack® Data Acquisition card in conjunction with a Toshiba Tecra 3 laptop using the Data Acquisition Factory Express® software was used for data logging. In addition, a Microsoft® Litecam VX-1000 webcam was installed at the side of the foot-well, capturing video at 60Hz.

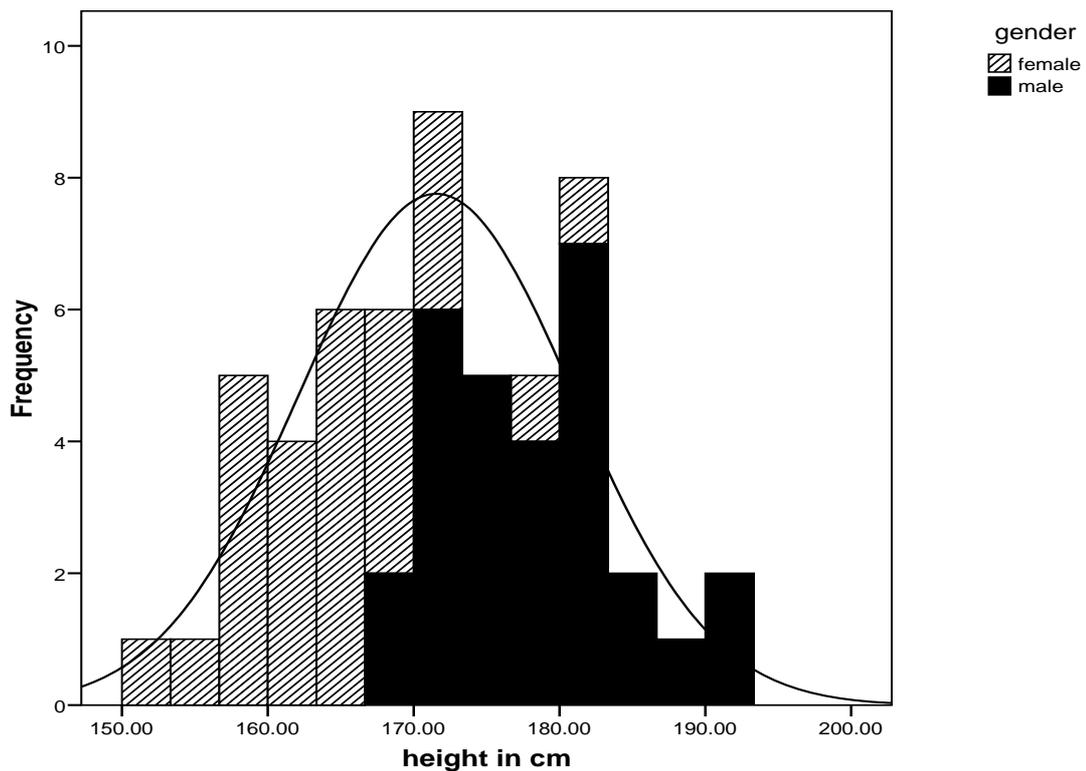


Figure 2: Stacked histogram of male/female participants' height

Realistic journeys?

Most typically the car was delivered to a participant's address early in the morning to commute to work and was collected in the evening from the same place. There were, however, cases where the participant opted to collect the car from its base (Loughborough University) and bring it back in the evening as well. For practical reasons, especially in the case of the car being delivered, the delivery driver would often sit in the passenger seat. The participants were aware that the aim was to monitor their "normal" driving, but didn't know exactly what aspect was being monitored. In summary, there is no apparent reason why the braking data collected should not be representative of the drivers' typical braking activity whilst making the trips that were undertaken.

Measurements

Both quantitative and qualitative pedal operation data were collected. The main measurements included throttle pedal angle change – mainly during release (“throttle-off”), force (and pressure) applied on the brake pedal surface and force (and pressure) applied on the clutch pedal surface. “Throttle-off” is the release of the throttle pedal that results in some deceleration of the vehicle, and is therefore either part of the braking sequence or a form of braking in itself. A camera in the foot well provided qualitative data on foot movement and pedal operation.

Results

In observational studies of this size and this depth the amount of data captured is such that analysis can demand even more time than data acquisition itself. Only some first results are presented here. These are: descriptive exploration of brake and throttle pedal operation in relation to vehicle deceleration, comparison between genders and examination of interaction of the main variables with demographics (age, experience, annual mileage, height and weight).

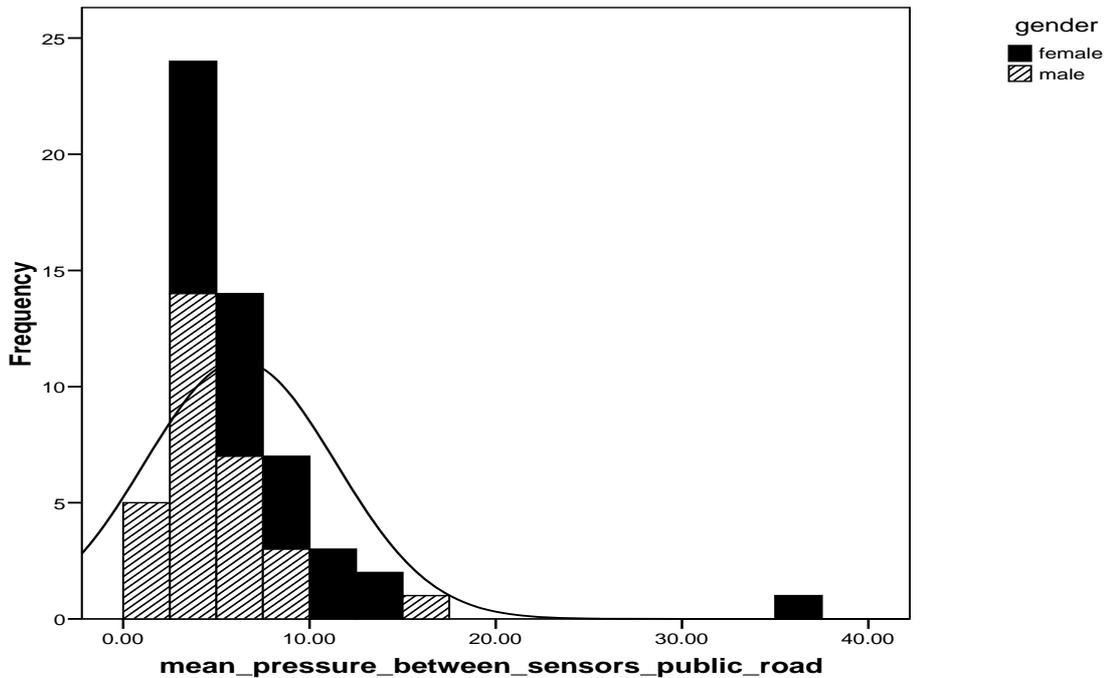


Figure 3: Stacked histogram of average forces applied on each sensor on the brake pedal (all values in Newtons)

Figure 3 presents the distribution of average forces applied on each sensor on the brake pedal during driving (values in Newtons). To make those values more understandable and usable, we need to convert them to pressure on the pedal surface (in Pascals). Those values can be found in table 1. The average pressure on the brake pedal was 78630.18 Pa with a standard deviation of 65623.6 Pa. Group statistics indicate that female drivers tended to apply higher forces on the brake pedal with an average of 100920.85 Pascals compared to 59215.82

Pascals for male drivers (Table 2). Further analysis using a T-test indicated that the difference was statistically significant ($p=0.01$).

Table 1: Descriptives of pressure on the pedal and throttle-off angle change

	N	Minimum	Maximum	Mean	Std. Deviation
Mean pressure on brake pedal (Pascal)	58	.00	448549.68	78630.18	65623.60
Throttle-off angle change (50Hz)	56	.18	.56	.51	.07
Valid N	56				

In terms of throttle-off angle change, values were strongly concentrated around the mean point. The average angle change (50 Hz sampling) was 0.51 degrees, with a standard deviation of 0.07 (table 1). The average for male drivers was 0.5 degrees and the standard deviation was 0.06 degrees while for female drivers the respective values were 0.52 and 0.08 degrees.

Table 2: group descriptives of pressure on brake pedal and throttle-off angle change for male and female drivers

	gender	N	Mean	Std. Deviation	Std. Error Mean
Mean pressure on brake pedal (Pascal)	male	31	59215.72	41144.92	7389.85
	female	27	100920.85	80760.97	15542.46
Throttle-off angle change (50Hz)	male	29	.50	.065	.012
	female	27	.52	.075	.014

Table 3: Male and female percentiles of brake pedal pressure (all values in Pascals)

<i>percentiles</i>	<i>gender</i>	
	male	female
5	8407.64	33824.45
10	15333.37	37852.10
25	37503.18	54203.82
50	48848.40	82101.91
75	76777.07	120926.11
90	113083.82	171286.11
95	156585.98	342657.45

Further analysis of the interaction of mean brake pedal pressure and throttle-off rate against age, experience, height, weight and annual mileage revealed no statistically significant correlations. All probability values were above the typical $\alpha=0.01$ criterion. Statistically

significant correlations were found between age and driving experience ($R=0.95$, $p=0.0001$) and between height and weight of participants ($R=0.65$, $p=0.0001$).

Table 3 presents the estimated percentiles of brake pedal pressure. It is obvious that female drivers were applying much higher forces on the pedal during braking. For example the estimated 5th percentile female (about 33kPa) is more than four times harder on the pedal than the 5th percentile male (about 8kPa).

Discussion

The study presented here featured some advantages over the previously quoted studies, especially in the methods used. Participants were recruited through advertising and word of mouth, without the use of any incentives that would appeal to a specific population. A normal distribution curve fitted well on height and weight data of participants (figures 1-2). This is particularly important as size of drivers could affect their posture (Porter & Gyi, 1998) in the vehicle and thus their operation of the pedal controls. The sample size was over 50 drivers and almost every age group was represented.

The first interesting result of the analysis is the difference between genders on force exerted during brake pedal operation. Considering both the results from Eaton's experiments (1970) as well as the data provided by Humanscale pedal controls (Diffrient, Tilley, & Harman, 1993), it is somewhat contradictory that the women exerted greater pedal force than the men. In these early studies small female drivers were used as a criterion for the minimum acceptable resistance of pedal control. Current results suggest that in everyday driving female drivers brake harder than male drivers. There seems to be a difference between what is theoretically expected according to muscle strength and what happens in action. However, it should be acknowledged that the studies measured variables related but not identical. Maximum possible force during operation, which was the scope of Eaton's study using small females in the '60s, is not the same as the actual force drivers apply when they drive on a public road, in a real car, in 2008. On the other hand, if the pressure values above are adjusted to the area of the brake pedal (about 20cm²), then the force values become very similar to the recommended values in Humanscale (4 – 30 N). And although Humanscale's recommendation is somewhat too wide (it actually corresponds to 1st – 10th %ile male braking force in the current study), in practical terms it is a realistic guideline as it falls within the lower range of forces encountered in the present study.

The second major comment concerns the implications of these data in relation to modern active safety systems and Emergency Brake Assist (EBA) in particular. There are some field studies suggesting significant contribution of such systems in rear-end collision mitigation (Breuer, Faulhaber, Frank, & Gleissner, 2007) and extended studies have attempted to identify the distinction between "normal" and "emergency" brake characteristics for the purpose of devising successful system specification (Kassaagi, 2001; Perron, Kassaagi, & Brissart, 2001). The size of the standard deviation in force/pressure applied on the brake pedal points towards a variation that cannot be accommodated by a constant threshold of activation, as most current systems do. A quick view of table 3 indicates that the average brake pressure quadruples between 25th percentile male and 75th percentile female drivers. Thus, it is highly unlikely that a single triggering value in brake force/pressure could accommodate this amount of variance.

On the contrary, the distribution of the throttle-off measurements showed strong concentration around the mean. This trend could be incorporated in the specification of relevant systems (and it already is in some versions of EBA). However, it remains to be seen

what the respective values in a certain emergency braking event might be. If there is a difference between the two conditions, then due to the limited variation, throttle-off is a more promising triggering variable. In addition, as it takes place before brake application, it has a temporal competitive advantage. Overall, results suggest that throttle-off is an important component of the braking task and safe longitudinal control of the vehicle.

The main limitation of this study is the use of a single vehicle by all participants. This study design allows room for possible confounding effects attributable to the particular vehicle concerned. Such a possibility could be evaluated by the use of alternative vehicles and subsequent comparison of results. Results from the early study by Eaton (1970) indicate that there is a minor increase in the forces applied on the brake pedal as the size of the vehicle increases; therefore it is desirable to put that to the test again. Ideally, the instrumentation of the actual vehicles owned and driven by the drivers should be considered in future studies. The second limitation of the study has to do with the size of the sample. Fifty-eight drivers is considered to be a potentially representative number: however a greater number and the inclusion of drivers from other areas of the country, and, ideally, of the world would be desirable. To improve confidence in the data reported so far, the sample size should be increased and other car models used in a more significantly resourced study.

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