ARE EXPECTED AND OBSERVED EFFECTIVENESS OF EMERGENCY BRAKE ASSIST IN PREVENTING ROAD INJURY ACCIDENTS CONSISTENT?

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Paper Number 05-0268

ABSTRACT

This paper proposes to estimate and to compare the expected and the observed effectiveness of the Emergency Brake Assist (EBA) in terms of reduction in injury accidents in France. The evaluation of the expected effectiveness of EBA is based on the simulation of the reduction in injuries in non-EBA cars which could result in lower collision speeds resulting themselves in higher mean deceleration, would EBA have been available and applied in those cars. A sample of fatal police reports, for which most of the vehicles involved in an accident, braking distance, collision speed and injuries outcome are available, is used for the simulation.

The evaluation of the observed effectiveness of EBA follows a 3-steps process:

- The identification, in the French National injury accident census, of accident-involved cars for which the determination of whether or not the car was fitted with EBA is possible. A sample of 917 cars involved in injury accidents occurred from January 2000 to June 2004 was selected.
- The identification of accident situations for which we can determine whether or not EBA is pertinent.
- The calculation, via a logistic regression, of the relative risk of being involved in an EBA-pertinent accident for EBA equipped cars versus unequipped cars, divided by the relative risk of being involved in a non EBA- pertinent accident for EBA equipped cars versus unequipped cars. This relative risk is assumed to be the best estimator of EBA effectiveness.

Both evaluations result in a good effectiveness of EBA. Furthermore, the rather consistent estimations out coming from expected (-7,5 % of car occupants fatalities, -10 % of pedestrian fatalities) and observed (-11 % of overall injuries) effectiveness of EBA validates the methodology used for the expected effectiveness.

INTRODUCTION

Emergency Brake Assist (EBA) detects the speed or the brake force at which the driver presses the brake pedal, and applies all available power boost if this speed or this force exceeds a certain threshold, considering that the driver is in an emergency situation. ABS regulation is then reached sooner. Therefore, Emergency Brake Assist can potentially reduce overall stopping distance by eliminating the delay caused by a common human tendency of not braking hard enough or soon enough. This reduction might end up with a reduced collision speed and thus with a crash avoidance or a mitigation of its consequences..

EBA is being a topic of considerable interest since the late 1990s because it might likely concern a high number of accidents. In 2004, in Europe (25 countries), more than 2 000 000 road users were slightly or seriously injured and 50 000 lost their lives (source: CARE database, 2004). It is unknown how many of these crashes resulted from lack of braking performance, i.e. EBA-pertinent crashes. The CARE database does not record such information. Consequently, the magnitude of these accidents is not accessible from European intensive databases and must be estimated from National data and accident in-depth databases. Based on French estimates, out of the 90 081 injury accidents recorded in 2003, 75 352 (83 %) involved at least a passenger car. On the other hand, Alleaume et al. showed that about 70 % of the car drivers that should have braked before the crash effectively did (Alleaume et al., 1998), the others 30 % did not. And last, Kassaagi et Perron showed that, in an emergency situation, about 50 % of the drivers reach the ABS regulation whereas 50 % would need to be helped (Kassaagi et Perron, 2001). Consequently, we estimate that approximately 0.83 * 0.7 = 0.58 (58%) of all injury accidents could be concerned with effective braking, out of these 0.58 * 0.5 = 0.29 (29 %) could be concerned with EBA, i.e. roughly 580 000 injured persons and 14 500 fatalities in Europe.

As for ESP for which the literature is now abundant (Zobel et al., 2000; Sferco et al., 2001; Langwieder et al., 2003; Aga et Okada, 2003; Tingvall et al, 2003; Unselt et al., 2004; Becker et al., 2004; Page et Cuny, 2004; Farmer, 2004; Dang, 2004), and as EBA is more and more fitted in modern cars, its effectiveness in terms of its capacity to avoid accidents and save lives must be addressed.

We have found only two published studies addressing, at least partially, this issue. Actually, they are addressing more specifically the safety benefits expected from pedestrian protection crash tests (Hannevald et Kauer, 2004, Lawrence et al., 2004). But they also state that, in any case, EBA is expected to be a good complement to these tests in preventing pedestrian and pedal cyclists injuries.

Evaluating the expected effectiveness of a safety measure (before it is brought to the market) is obviously interesting as it can eventually help stakeholders in deciding whether or not a technology is promising. That kind of evaluation is nevertheless demanding simulation techniques and sometimes heavy assumptions that can be, to a certain extent, questionable. They have to be validated. On the other hand, evaluating the observed effectiveness of a safety measure is by no means prospective but can help stakeholders in deciding the generalization of this measure if it is proved to be effective for a fleet of cars that have effectively been equipped with such a technology. Both types of evaluation are then pertinent.

Our aim, in this paper, is first to propose an evaluation of the observed effectiveness of EBA on any kind of injury accidents and not only on accidents involving vulnerable road users. But we also aim at comparing the observed and the expected effectiveness of the Emergency Brake Assist (EBA) in terms of reduction in injury accidents in France. This comparison will serve as a validation of the expected effectiveness techniques.

EXPECTED EFFECTIVENESS OF EBA

Data

This part of the study is based on French fatal road traffic accidents involving non-ABS equipped passenger cars for which the presence of skid marks (a vast majority were on a dry road surface) was reported by the Police. The database is constituted with police reports collected by the LAB in 1991. An update of this database is currently on course with the collection of fatal accidents occurred in 2002 and 2003 but was not completely available at the time of study and could not be used for our purpose.

Method

From the length of the skid marks (*db* – braking distance), the mean deceleration (*a*) and the impact speed (*Si*) estimated from vehicle photos and contents of the police reports, it is possible to calculate vehicle speed (*Sb*) at the start of the skid marks and at brake pedal action (*Sa*).

We assume that EBA can reduce brake activation time by 50%. It is then possible to calculate a new impact speed using the existing speed Sa and applying the reduced brake activation time. The new, reduced impact speed Si obtained with EBA results in, with the exception of extremely violent crashes, a decreased risk of being fatally injured for the vehicle occupants. This decreased risk is calculated, according to the different crash types considered, by using the observed fatality rates for the impact speed concerned.

This method is applied to accidents involving a vehicle which left skid marks prior to impact, as shown in the following example : in a fatal front to side collision, impact speed is estimated at 70 km/h (Si) and dry road surface skid marks prior to impact are measured to be 15 meters long (db). The following hypotheses are made:

- The braking deceleration (a) on this 15 meter distance (db) is 7 m/s² (mean value for non ABS vehicles from the 1990s).

- The brake activation time (t) is 0.7 s (mean time measured during driver behavior tests in emergency situations).

Si, Sa and total distance (*dt*) traveled between the point of impact and the vehicle's position at the time of brake activation (which is the sum of the braking distance db and the distance traveled during brake activation (*da*)) can then be calculated using the following formulae:

$$Sb^2=Si^2 + 2.a.db \quad (1).$$

$$Sa=Sb + a/2.t \quad (2).$$

$$dt= db + da = db + (Sa – Sb).t \quad (3).$$

We then make the hypothesis that the time needed to reach maximized braking is halved, corresponding here to 0.35 seconds. From the speed Sa we can then calculate, with the reduced brake activation time, the new speed Sb1 corresponding to the start of maximum braking and the new position of the vehicle relative to the point of impact (which is also the new braking distance db1) and hence the new impact speed Si1, <u>using the same deceleration as before</u>.

$$Sb1=Sa - a/2.t/2 \quad (4).$$

$$da1= (Sa - Sb1). t/2 \quad (5).$$

$$db1= dt - da1 \quad (6).$$

$$Si1^2= Sb1^2- 2.a.db1 \quad (7).$$

In our example, the impact speed with EBA (Si1) drops to 64 km/h from 70km/h without EBA (Si) (Table 1).

Table 1.
Example of calculation of new impact speed due to EBA

Without EBA	
Impact speed (Si)	70 km/h
Braking distance (db)	15 m
Speed at start of skid marks (Sb)	87.3 km/h
Brake activation time	0,7s
Distance traveled during brake activation (da)	17,8 m
Speed at start of brake pedal action (Sa)	96.1 km/h
With EBA	
New brake activation time	0.35 s
Distance traveled during brake activation (da1)	9.1 m
Speed at start of skid marks (Sb1)	91.7 km/h
Braking distance (db1)	23.7 m
Impact speed (Si1)	64.1 km/h

Figure 1 gives the percentage (or the fatality risk) and cumulative percentage of fatalities for vehicle occupants seated on the impact side of laterally impacted vehicles in fatal front to side collisions involving two passenger cars. For collision speeds in excess of 100 km/h, the 5 km/h or 10 km/h speed decrease due to EBA will obviously have no risk reduction effect on the occupants of laterally impacted vehicles. However, if the speed decrease with EBA brings this value below 90 km/h (corresponding to between 85 and 90% of cases in this crash configuration), fatality reductions may be obtained.

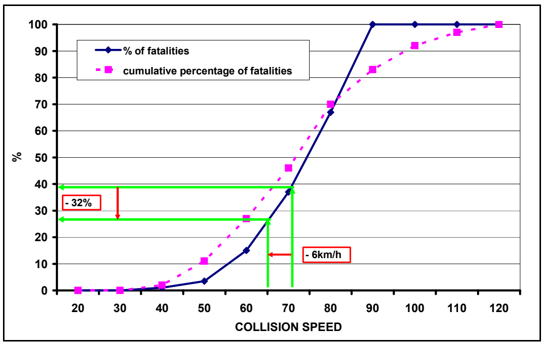

Figure 1. Distribution of fatalities and fatality risk curve according to collision speed (Source: LAB).

In the example given above, where impact speed is reduced by 6 km/h from 70 to 64 km/h, the fatality risk is reduced by 32% (38% to 26%). The same speed reduction will have a different effect on the fatality rate according to the violence of the crash, diminishing as impact speed increases, before disappearing altogether for the most serious impacts.

This method was applied case by case for each crash configuration. For a given impact speed and with the calculated reduction in this speed with EBA, the reduction (or not) of the risk of being fatally injured can be inferred.

Results

This method was applied to all accidents in which a car left skid marks before hitting an obstacle head on (other vehicle or fixed obstacle) and in which a car occupant was fatally injured.

For all fatal accident configurations (with the exception of crashes involving pedestrians and two-wheelers), frontal impact (with or without skid marks) is observed in 60% of cases (figure 2).

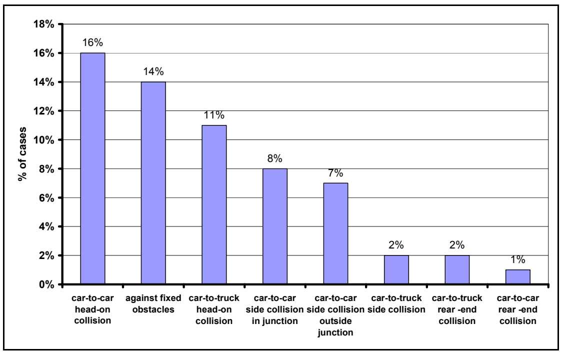

Figure 2. Distribution of fatal crashes resulting in Frontal impact (Source: LAB).

The percentage of cases occurring on dry roads varies from 44% (front to side non-junction impacts) to 81% (front to side junction impacts).

- The percentage of cases in which one or both vehicles leave skid marks on a dry road varies enormously in fatal accidents. In frontal impacts against fixed obstacles, skid marks are found in only 10% of cases whereas in front to side junction crashes involving two cars, skid marks are found in 54% of cases. This difference is mainly due to the high proportion of drivers under the influence of alcohol in fatal crashes against fixed obstacles (50%) compared to junction collisions. In head-on collisions between two cars, skid marks are observed for one vehicle in 28% of cases and for both vehicles in 3% of cases.

Of all fatal accidents involving non-ABS equipped cars, regardless of crash configuration, 11% involve skid marks on a dry road leading to a frontal impact against an obstacle (figure 3).

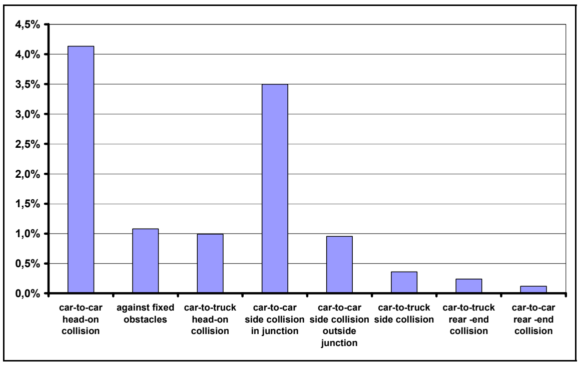

Figure 3. Distribution of fatal crashes with skid marks (Source: LAB).

Assuming that on wet road surfaces the braking distribution (without skid marks) is similar to that on dry roads, the percentage of cases where EBA would be beneficial rises from 11 to 16%.

The study was carried out on 203 fatal accidents for which vehicle photos enabled the estimation of crash violence. The potential reduction in fatalities, estimated using all the aforementioned hypotheses, is between 19% and 38%, depending on the different crash types, as shown in tables 2.

Tables 2.
Potential reduction in fatalities by EBA

Crash type	Number of cases analyzed with skid marks on dry road	% of victims saved for the analyzed cases
Front to side junction collision between two cars	66	36%
Front to side non-junction collision between two cars	17	19%
Head-on collision between two cars	98	24%
Collision against fixed obstacle	32	38%

Crash type	Proportion of all fatal accidents	Proportion of cases with braking	% of all fatalities saved
Front to side junction collision between two cars	8%	54%	1,6%
Front to side non-junction collision between two cars	7%	31%	0,4%
Head-on collision between two cars	16%	31%	1,2%
Collision against fixed obstacle	14%	10%	0,5%

We can thus estimate a reduction of between 25% and 30% of occupant fatalities for all accidents where braking is observed, which corresponds to a reduction of between 4% and 5% of the total number of fatalities in road accidents (25% to 30% of the 16% of cases involving a frontally impacted car which braked prior to impact).

Furthermore, as stated in the introduction, various studies of driver behavior tests in emergency situations with non-EBA equipped vehicles have shown that, for 100 cases where braking was observed, between 20 and 30% of drivers do not apply sufficient pressure on the brake pedal to reach the full braking potential. If, in an emergency situation, EBA reduces brake activation time and also allows maximized braking in the case of driver "failure", larger fatality reductions are possible.

Let us now suppose that, for fatal accidents involving non-ABS equipped vehicles which have not left skid marks on the road, the drivers who braked only reached a deceleration of 4 or 5 m/s^2 and that EBA would have given sustained 7 m/s^2 braking. When compared with identical fatal accident situations (impact speed and braking distance) where braking was maximized, the increased deceleration with EBA (from 4 or 5 to 7 m/s^2) would give greater reductions in impact speeds and thus a potential gain of between 45% and 75% in the number of fatalities.

Working with the hypothesis that the distribution of accident characteristics (braking distance at "reduced" deceleration) for the different collision types is similar to that for maximized braking, the potential gain in fatalities is around 2.5 to 4% (approximately a 60% gain for between 4% and 7% of the cases). **When we consider all car occupant fatalities, EBA with maintained maximum braking force during the emergency phase would reduce the number of fatalities by between 6.5 % and 9 %.**

A similar study was carried out on pedestrians who were hit and killed by cars. 25% of cases occurred on dry roads with skid marks reported. Using the measured length of the pre-crash skid marks and calculated speeds, the potential gain with **EBA for pedestrians hit and killed by all vehicle types is around 10 to 12%.**

OBSERVED EFFECTIVENESS OF EBA

Method and data

As in the ABS and ESP studies carried out in the past by Evans (1998), Kullgren et al. (1994), Tingvall et al. (2003), and Page et Cuny (2004), we used a method that refers only to accident data independent of exposure data. As in our ESP study (2004), our method consists of 3 steps:

- The identification, in the French National injury accident census (Gendarmerie Nationale only), of accident-involved cars for which EBA equipment or non-equipment is known.

- The identification of accident situations for which we can determine whether or not EBA is pertinent (e.g. EBA is pertinent for cars coming up at a junction, with the right of way, whereas another road user is pulling out of the stop whilst it is not pertinent for cars hit by the rear).

- The calculation, via a logistic regression, of the relative risk of being involved in an EBA-pertinent accident for EBA-equipped cars versus non-equipped cars, divided by the relative risk of being involved in a non EBA-pertinent accident for EBA-equipped cars versus non-equipped cars. This relative risk is currently assumed to be the best estimator of EBA effectiveness.

First step

In France, the identification of cars involved in an injury accident is not that easy. Cars are recorded in the national accident census via a code, the so-called CNIT code, which the police copies from the vehicle registration document. Unfortunately, 50 % of the codes are not directly identifiable due to errors in the completion of the statistical form. Furthermore, for the remaining 50 %, there is no bijection between the code and the determination of whether a car is or is not equipped with a given device. Consequently, instead of identifying whether a car, selected from the accident-involved cars is EBA-equipped, we had to choose a set of cars for which the information was easily accessible and then identify these cars in the accidents according to their make and model, which is easier via the CNIT. This data limitation led us to retain only two makes and models: the Renault Laguna and the Peugeot 406. There are two versions of the Laguna. The Laguna 1, was produced in the late 1990s and early 2000s without EBA. In January 2001, Renault launched the Laguna 2, with EBA as standard equipment. It was then possible to distinguish the two Lagunas in the accident census using the CNIT (make and model) and the first registration date. Regarding the Peugeot 406, EBA has been fitted on the car since 2000.

We selected a sample of 2061 Renault Laguna and Peugeot 406 cars involved in injury accidents occurring from January 2000 up to mid 2004 in France. These are all the Lagunas and 406 we were able to identify in the national accident census. We therefore had to assume that the residual unidentifiable chosen cars, due to errors in typing the car identification code, were randomly distributed among EBA-pertinent and non-pertinent accidents. These accidents are assumed to be very few as we did our utmost to identify all the Lagunas and 406.

Second step

The method requires the allocation of accidents into EBA-pertinent and non-pertinent accidents. We took this information from the national census by combining several variables such *pre-accidental maneuver*, *number of vehicles involved*, and *type of obstacle*. We ended up with a list of 34 accidental situations (table 3). We were not actually interested in the accidents per se, but rather the accident situations, the difference being that the accident situation is linked to a driver-vehicle unit (Page et al., 2004). A single vehicle accident has a single situation. In a two-vehicle accident, each driver has a specific accident situation corresponding to the circumstances in which he finds himself. For example in a crossing accident at a junction, the first situation corresponds to the user who pulls out of the intersection after stopping at a stop sign. The second situation corresponds to the driver with right of way who has to cope with a vehicle suddenly crossing his carriageway. This is the reason why we chose to build an accident situation list rather than an accident list (Table 3).

Table 3.
Accident situations and
EBA pertinent-situations

Accident situation	Main relevance
Loss of control and guidance problem	
Single car accident. Loss of control on a straight road	EBA pertinent if frontal impact
Loss of control on a straight road. Collision with an opponent	EBA pertinent
Single car accident. Loss of control in a bend	EBA pertinent if frontal impact
Loss of control in a bend. Collision with an opponent	EBA pertinent
Single car accident. Loss of control at a junction	EBA pertinent if frontal impact
Accident involving a pedestrian	
Car confronted to a pedestrian walking, playing, running, along the roadway, crossing the road or hidden by an obstacle	EBA pertinent
Car moving backward and hurting a pedestrian	
Car-to-vehicle accident out of junctions	
Adverse to the vehicle that looses control in a bend	EBA-pertinent
Adverse to the vehicle that looses control on a straight road	EBA-pertinent
Rear-end collision. Hitting car	EBA-pertinent
Rear-end collision. Hit car	

Car changing his lane	EBA-pertinent
Car facing an obstacle	
Overtaking car	EBA-pertinent
Parking or parked car	
Car making a left turn	
Car in which an occupant opens his door	
Car making a U turn or crossing the road	
Car-to-vehicle accidents at junctions	
Car driver in insertion or turning left or right in around about	
Car driver confronted to a vehicle in insertion or turning left or right in a round about	EBA-pertinent
Crossroads. Driver at fault going straight ahead	
Crossroads. Driver not at fault going straight ahead confronted to driver at fault going straight ahead in the perpendicular direction	EBA-pertinent
Crossroads. Driver going straight ahead confronted to driver at fault turning left or right to the perpendicular road	EBA-pertinent
Crossroads. Driver turning left or right	
Same road. Different directions. Car driver at fault confronted to not at fault driver going straight ahead	EBA-pertinent
Same road. Different directions. Car driver not at fault confronted to at fault driver going straight ahead	EBA-pertinent
Same road. Different directions. Car driver confronted to a driver turning left or right	EBA-pertinent
Same road. Different directions. Car driver turning left or right confronted to a driver going straight ahead	
Same road. Same directions. Car at fault hitting another vehicle going straight ahead	EBA-pertinent
Same road. Same directions. Car driver not at fault going straight ahead hit by another vehicle	
Same road. Same directions. Car driver hitting another vehicle turning left or right	EBA-pertinent
Same road. Same directions. Car driver turning left or right hit by another vehicle	
Car driver not at fault hitting another vehicle making a U turn	EBA-pertinent

For each accident situation, we stated whether it was EBA-pertinent or ESP-pertinent, or neither ESP nor EBA pertinent. We made this distribution on the basis of our LAB expertise with respect to in-depth analysis of accidents investigated on-scene.

EBA-pertinent accidents belong to one of the four following accident groups:

- Single car accidents with a frontal impact against a fixed obstacle. Single car accidents with roll over were assumed to be alcohol or drowsiness related and in those cases, braking doesn't appear to be relevant.

- Accidents involving a pedestrian, except those where the car was moving backward.

- Car-to-vehicle accidents situations where the collision is supposed to be frontal. The hitting cars involved in a rear end collision are also part of the EBA-pertinent accident situation.

- Car-to-vehicle accidents situations occurring at a junction mainly where a right-of-way car is confronted to an at-fault car going straight ahead or turning left/right, whatever the cars are on the same road or not.

There are two kinds of Non EBA-pertinent accidents: those for which ESP is pertinent and those for which it is not. Because ESP was the other main active safety innovation on Laguna 2 compared to Laguna 1 and because the Peugeot 406 taken into consideration in the analysis are not ESP-fitted, integrating ESP-pertinent accidents in the sample of non EBA-pertinent situations could have generated a bias in the estimation of EBA effectiveness.

We finally decided to limit Non-EBA pertinent accidents to a subset of accidents for which ESP does not apply. Furthermore Non-EBA pertinent accident situations, such as U-turn, which concern only a small number of drivers and which were found to be quite negligible have not been taken into account in the analysis.

The influence of passive safety enhancements will be covered in the discussion section.

Third step

Effectiveness is highly dependent on the effectiveness indicator. We must therefore choose it carefully, according to available data. Concretely, in our study, the effectiveness E is estimated by (8).

$$E = 1\text{-}OR = 1 - [(A*D) / (B*C)] \qquad (8).$$

With OR, the odds ratio, A, B, C, D being the numbers of accidents with respect to EBA, as explained in table 4.

Table 4.
Distribution of accidents for the calculation of the odds ratio (OR)

	EBA-equipped cars	Non EBA-equipped cars
EBA-pertinent accidents	A	B
Non EBA-pertinent accidents	C	D

After several assumptions, and noticeably the assumption that the accident sample is drawn randomly from the accident census, we can show that (e.g. Hautzinger, 2003) :

$$OR = \frac{R_{AS}}{R_A} = \frac{\dfrac{R_{AS-S}}{R_{AS-NS}}}{\dfrac{R_{ANS-S}}{R_{ANS-NS}}} \qquad (9).$$

With:

- Ras-s is the risk of being involved in an accident where EBA is assumed to be pertinent for an EBA-equipped car.

- Ras-ns is the risk of being involved in an accident where EBA is assumed to be pertinent for a non EBA-equipped car.

- Rans-s is the risk of being involved in an accident where EBA is assumed not to be pertinent for an EBA-equipped car.

- Rans-ns is the risk of being involved in an accident where EBA is assumed not to be pertinent for a non EBA-equipped car.

In other words, the odds ratio OR, formulated by (9), has a comprehensible interpretation. Assuming that EBA has no effect at all on accidents in which it is not assumed to be pertinent, (Rans-s / Rans-ns) is assumed to be equal to 1. This commonly supposes no driver adaptation to EBA with for example higher risk taking or higher driving speed. Consequently, the odds ratio measures the relative risk of being involved in an EBA accident for EBA-equipped versus non-equipped cars.

In practice, table 4 only enables the calculation of the crude odds ratio, irrespective of potential other explanatory variables. The adjusted odds ratio is then estimated via a logistic regression. It enables confounders such as: Driver age and gender; Vehicle age and Year of accident; Pavement status (whether the pavement was dry or wet); Location of accident … to be taken into consideration. No reliable information about seat belt use was available.

Results

Simple statistics

The limitation of the accident situations to those related specifically to EBA and those related to neither ESP nor EBA lowered the number of situations to be considered. Selections were also applied to retain only ABS-fitted cars. Accidents occurring on motorways were excluded from the sample. We finally retained 917 out of the initial 2061 cars. Unfortunately, the small sample size can generate unstable coefficients in logistic regression and/or large confidence interval of the odds ratio. We'll come back to this issue in the discussion section.

Tables 5 to 10 show the distributions of each explanatory variable. For most of them, the distribution does not show cells sufficiently unbalanced to disturb the analysis.

Table 5.
Location of accidents according to EBA status

Location	EBA not fitted in the car	EBA fitted in the car	Total
inside urban areas	143 (26%)	106 (29%)	249 (27%)
outside urban areas	410 (74%)	258 (71%)	668 (73%)
Total	553	364	917

Table 6.
Pavement status according to EBA status

Pavement status	EBA not fitted in the car	EBA fitted in the car	Total
Dry	127 (23%)	74 (20%)	201 (22%)
Wet	426 (77%)	290 (80%)	716 (78%)
Total	553	364	917

Table 7.
Gender of the driver according to EBA status

Gender	EBA not fitted in the car	EBA fitted in the car	Total
Female	116 (21%)	73 (20%)	189 (21%)
Male	437 (79%)	291 (80%)	728 (80%)
Total	553	364	917

Table 8.
Driver age according to EBA status

Driver age	EBA not fitted in the car	EBA fitted in the car	Total
18-24 years old	43 (8 %)	19 (6%)	62 (7%)
25-34 years old	115 (21%)	55 (15%)	170 (19%)
35-44 years old	113 (20%)	100 (27%)	213 (23%)
45-54 years old	127 (23%)	80 (22%)	207 (23%)
55-64 years old	82 (15%)	59 (16%)	141 (15%)
65 years old and over	73 (13%)	51 (14%)	124 (13%)
Total	553	364	917

Table 9.
Vehicle age according to EBA status

Vehicle age	EBA not fitted in the car	EBA fitted in the car	Total
Less than 1 year old	53 (10%)	187 (51%)	240 (26%)
1 year old	115 (21%)	110 (30%)	225 (24%)
2 years old	161 (29%)	46 (13%)	207 (23%)
3 years old	108 (19%)	19 (5%)	127 (14%)
4 years old	78 (14%)	2 (1%)	79 (9%)
5 years old and over	38 (7%)	-	38 (4%)
Total	553	364	917

Table 10.
Year of accident occurrence according to EBA status

Year of accident	EBA not fitted in the car	EBA fitted in the car	Total
2000	178 (32%)	46 (13 %)	224 (24%)
2001	156 (28%)	97 (27%)	253 (28%)
2002	151 (28%)	117 (32%)	268 (29%)
2003	45 (8%)	67 (18%)	112 (12%)
January-June 2004	23 (4%)	37 (10%)	60 (7%)
Total	553	364	917

Tables 9 and 10 show an evidence of unequal distribution of EBA status according to the age of the vehicle and the year of the accident. The EBA fitted cars are newer than the cars not fitted with EBA. This is not surprising, EBA being a new system not fitted on car before the year model 2000 or 2001 according the model of the car.

It is then expected that Year of accident and Vehicle age would be significant explanatory variables in the regression.

Crude odds ratio

Table 11 displays the repartition of accident situations according to EBA equipment.

Table 11.
EBA status of cars according to their involvement in EBA pertinent situations

	EBA fitted on the car	EBA not fitted on the car	Total
EBA pertinent accident situations	277	436	713
Non EBA pertinent accident situations	87	117	204
Total	364	553	917

From this table, we can calculate the crude odds ratio, OR = (277*117) / (436*87) = 0.85. We can also calculate the confidence interval of the odds ratio [0.62;1.16]. The effectiveness is then calculated by (8): 1-0.85=15 %. The risk of being involved in an EBA-pertinent accident for EBA-equipped cars is 15 % lower than the same risk for non-equipped cars. However, as expected, this result is not statistically significant because of the small sample size.

This first result has to be validated by a more sophisticated analysis taking possible confounders into consideration. This was done using logistic regression.

Logistic Regression

Logistic regression enables the estimation of the adjusted odds ratio and its confidence limits. The crude odds ratio is then *adjusted* by the values of the explanatory variables. The variable of greatest interest is, needless to say, the presence of EBA in the car. The other variables are taken into consideration as confounders and also to counter the potential bias due to the limitation of data.

Table 12 presents the results of the logistic regression. It should be remembered that logistic regression requires the fixing of a reference point for each variable (i.e. one of the values of the variable), which is then used to explain the results across the entire variable. The reference points for each explanatory dimension are highlighted *in italics* in Table 12.

Table 12.
Results of the Logistic Regression

Number of observations = 917
EBA-pertinent cases : 713 / Non EBA-pertinent cases : 204
AIC : 967 --- SC : 1064 --- -2LogL : 927

	Odds ratio	min	max
EBA			
EBA fitted on the car	**0.81**	**0.48**	**1.38**
EBA not fitted on the car	-	-	-
Driver age			
18-24 years old	2.36	1.04	5.34
25-34 years old	1.59	0.95	2.67
35-44 years old	-	-	-
45-54 years old	1.36	0.84	2.18
55-64 years old	0.95	0.58	1.57
65 years old and over	0.86	0.51	1.45
Gender			
Female	0.76	0.51	1.13
Male	-	-	-
Car model			
Peugeot 406	1.24	0.84	1.77
Renault Laguna	-	-	-
Vehicle age			
less than 1 year old	-	-	-
1 year old	1.18	0.72	1.95
2 years old	1.18	0.66	2.11
3 years old	0.82	0.41	1.66
4 years old	0.72	0.30	1.71
5 years old and over	0.72	0.22	2.33
State of the pavement			
Dry	-	-	-
Wet	1.44	0.94	2.20
Location			
Inside urban areas	-	-	-
Outside urban areas	2.05	1.46	2.88
Year of the accident			
2000	-	-	-
2001	0.80	0.49	1.32
2002	1.10	0.63	1.93
2003	1.40	0.65	2.98
January - June 2004	0.76	0.31	1.87
Percent concordant pairs : 64.6 Somers'D=0.3 Gamma=0.3 Tau-a=0.1 c=0.65			

The adjusted odds ratio correspondent to EBA is estimated 0.81 and its confidence interval [0.48;1.38]. It is not very different from the crude odds ratio. **Based on the crude and on the adjusted odds ratio, we can then confirm that EBA is apparently effective in reducing the risk of being involved in an EBA-pertinent accident for EBA-equipped cars versus non-equipped cars. Effectiveness is estimated to be 19 % of pertinent crashes. However, this estimation is not statistically significant** and holds only for our selection of cars: the Renault Laguna and the Peugeot 406.

DISCUSSION

Our aim, in this paper, was to propose an evaluation of the observed effectiveness of EBA on any kind of injury accidents and to compare the observed and the expected effectiveness of the

Emergency Brake Assist (EBA) in terms of reduction in injury accidents in France.

To estimate EBA expected effectiveness, we selected a sample of fatal accidents involving a passenger car occurred in France in 1991 for which we knew the impact speed, the initial speed, and the braking distance before the crash. Applying some assumptions about the EBA functioning (reduction in brake activation time, sustained braking, non behavioral adaptation), it is possible to estimate the reduced crash speed due to EBA. Then the use of fatality risk curves allows estimating the reduction in fatalities due to the reduction in collision speed for a series of types of collisions. Our result states that EBA with maintained maximum braking force during the emergency phase would reduce the number of car occupant fatalities by between 6.5% and 9% and pedestrian fatalities by about 10 % to 12%.

To estimate EBA observed effectiveness on all kind of accidents, we used a method that only refers to accident data irrespective of exposure data. The method consisted of 3 steps. First we selected makes and models of cars involved in injury accidents in France, from January 2000 to June 2004, for which the determination of whether or not the car is fitted with EBA is possible. It led us to conserve only Renault Laguna cars and Peugeot 406.

Then we identified 34 various accident situations and also split these accident situations into four groups according to whether they were ESP-pertinent, EBA-pertinent, ESP and EBA-pertinent or neither ESP nor EBA-pertinent. The identification of ESP as a potential avoidance or injury mitigation maneuver is necessary because the Laguna 2 are also equipped with ESP that could also be effective and act in combination with EBA. As we wished to measure only the effectiveness of EBA, we had to withdraw the ESP-pertinent accident situations from the analysis. Finally, we ended up with a sample of 917 accident situations, 713 being EBA-pertinent and 204 being non EBA-pertinent.

The estimation of the effectiveness of EBA was carried out using the adjusted odds ratio, which can be interpreted as the relative risk of being involved in an EBA-pertinent accident for a car fitted with EBA versus a car non fitted with EBA, divided by the relative risk of being involved in a non EBA-pertinent accident for a car fitted with EBA versus a car not fitted with EBA. This relative risk is assumed to be the best estimator of the EBA effectiveness.

The analysis focused on injury accidents only (injury accidents and fatal accidents combined). Braking pertinent accidents account for approximately 60 % of injury accidents in France. As the expected effectiveness is 19 % of pertinent crashes, the overall effectiveness, if 100 % of the fleet would be equipped with EBA, would be a 11 % reduction in overall injuries.

A series of implicit or explicit assumptions were made during the course of the evaluation and a few difficulties also arose from the data and method.

- The effectiveness indicator, i.e. the odds ratio, supposes that there is no driver adaptation to EBA, and especially that the non EBA-pertinent accidents are not affected by the presence of EBA.

- The effectiveness depends heavily on the breakdown of accident situations into EBA-pertinent and non-pertinent situations. Apart from classification errors due to the use of imprecise national accident census, we took care to withdraw accident situations that could be pertinent to another safety system such as ESP. On the other hand, this resulted in a small accident situations sample that reduced the stability and the accuracy of the effectiveness estimation (large confidence interval). A larger sample should be sought. In time, the number of identifiable cars in the national census will grow and we will be able to update our result.

- The effectiveness holds only for two makes and model of the M2 segment: the Renault Laguna and the Peugeot 406. This does not mean that the effectiveness holds for other cars and other segments.

We should seek for ways to integrate more cars into the sample while taking into consideration the differences in car makes and models. Once again, the increase in sample size and the variety of identifiable cars could be of great help in the future.

- That raises another crucial issue. The cars that we have compared, although identical in make and model for two of them, are completely different thanks to the dramatic improvements on the Laguna 2 concerning active and passive safety. It is natural (and proven) to consider that the likelihood of sustaining injuries in Laguna 2 is dramatically reduced compared to Laguna 1. The only problem that arises is to state whether or not this reduction is identical for EBA-pertinent and non-pertinent accidents. If it is the case, no bias is generated in the analysis. We haven't tested this hypothesis so far. We implicitly considered that it is true. Further work should address this important matter, especially regarding the types of impact subsequent to EBA-pertinent or not pertinent accident situations.

- EBA systems fitted in cars are not identical. EBA configuration depends on the suppliers as well as the instructions given to suppliers by the car manufacturers. It is impossible to state from our analysis which EBA system provides better results.

- We evaluated the short-term effect of EBA. The long-term effect might be different as drivers increase their awareness of EBA benefits. This could generate a driver adaptation and then a likely reduction of the EBA effect. Once again, an update of the study within a few years would eventually highlight this issue.

- As our sample size is small, we haven't been able to estimate the effectiveness of EBA for different car sizes and different weather conditions. We highlighted an overall effect while being unable to attribute this effect to certain types of cars or certain accident situations.

Now, we must answer the second of our questions: are expected and observed effectiveness of EBA consistent? The data available and the methodology choices are of course different: on one hand, we estimated a reduction in fatalities with simulation techniques and fatality risk curves, on the other hand, we used epidemiological techniques able to estimate a reduction in all injury accidents (and not only fatal, the sample size would have been too small). Assumptions are of course needed in both cases, and especially the absence of driver behavior adaptation that surely holds true at least in the short term. We ended up with estimates which are rather close but apply to accidents with different severities. The drop in fatalities was however expected to be higher than the drop in injury accidents as the fatality curve shows up promising effectiveness at high collision speeds (but less than 90 km/h). This is certainly due to the reduction of our sample to accidents for which skid marks were reported by the police. An extension of accidents for which braking could have been suspected by the police would have resulted in an higher effectiveness (but this information is not available).

In any case, EBA (and also ESP for which Sferco et al. anticipated in 2001 a high potential confirmed in 2003 and 2004 by epidemiological studies) efficiencies are very high and as the equipment rate is growing rapidly, these systems will definitely be a major contribution to further reductions in the road toll. They have already proven effectiveness and should be considered as major safety devices in the coming years, especially in combination with passive safety devices, for example pretensioners, load limiters and airbags, which have also proven a very high efficiency (-80 % of fatal thoracic injuries) and with other active safety devices.

From a purely research perspective, our ambition is now to go beyond the evaluation of one system independently of the others, to overcome the methodological difficulties and assess the effectiveness of passive and active safety systems acting in combination with one another.

ACKNOWLEDGMENTS

The authors also like to warmly thank Richard Driscoll (CEESAR) for his careful reading, remarks and English editorial comments.

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