REAL-WORLD BENEFITS OF ADAPTIVE HEADLIGHTS (ADHL) ON PASSENGER CARS IN SWEDEN

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Paper Number 17-0230

ABSTRACT

Adaptive headlights (ADHL) have been introduced by several car manufacturers as a technology to help the driver to better see in a curve in the dark. The headlights' horizontal aim is directed where the vehicle is heading based on the speed of the vehicle and the direction of the steering wheel. Previous research has suggested that adaptive headlights have significant real-world benefits in reducing injury crashes with passenger cars. Headlight evaluation has also been included in car rating protocols. However, there are few effectiveness figures for specific crash types or situations. The objective of this study was therefore to investigate the real-world benefits of adaptive headlights in different crash types in Sweden.

Swedish police reported injury crashes involving Volvo cars (MY 2006-2015) were included in this study. The fitment of ADHL and other safety features was determined by consulting electronic parts catalogues with the VIN of each individual car.

In total, 1,303 ADHL-fitted cars and 5,262 cars without ADHL were identified. The statistical analysis used odds ratio calculations with an induced-exposure approach. Daylight crashes were assumed to be non-sensitive for ADHL. The effectiveness of ADHL was estimated by calculating the odds ratios in darkness/daylight for single-vehicle crashes, crashes involving vulnerable road users as well as head-on and crashes at intersections.

ADHL were found to significantly reduce single-vehicle passenger car injury crashes in darkness by 39% (95% CI lower limit 11%). This is where the benefits of ADHL would be expected to become more evident, as the driver is assisted by the system through improved visibility. No significant reduction were found in other crash types. In two-vehicle crashes, ADHL may not be expected to provide significant benefits compared with conventional headlights.

As the proportion of single-vehicle crashes in darkness is rather limited in Sweden (3.5%), the overall benefits of ADHL were found to be 2%. Based on these findings, it may be doubtful that ADHL should be given great attention in rating schemes and assessment programs.

BACKGROUND

Adaptive headlights (ADHL) have been introduced by several car manufacturers as a technology to help the driver to better see in a curve in the dark. The headlights' horizontal aim is directed where the vehicle is heading based on the speed of the vehicle and the direction of the steering wheel.

Previous research has suggested that adaptive headlights could have significant real-world benefits in reducing passenger car crashes. Based on crashes in the USA, a study from the Insurance Institute for Highway Safety (IIHS) has estimated the ADHL could have the potential to prevent up to 142,000 crashes associated with poor visibility per year in the US [1]. It was estimated that ADHL would theoretically address 91% of non-fatal injuries crashes and 88% of fatal crashes that occur on curves at night. That would correspond to a reduction of 2% of all crashes, 4% of non-fatal crashes and 8% of fatal crashes [2].

In another study the American Highway Loss Data Institute (HLDI) used insurance claims to investigate the reduction of claim frequency in cars with ADHL compared to similar cars without. Passenger cars from Acura, Mazda, Mercedes and Volvo were included in the study which also controlled for influencing factors such as driver age and gender, garaging state and collision deductible [3]. Significant reductions in insurance claims for property damage liability and bodily injury liability were found for three out of four adaptive headlight systems. In Volvo cars with ADHL the property damage liability was reduced by 10% compared to Volvo cars of the same models without ADHL [4]. These findings could be a bit surprising since only 7% of police reported crashes in the US occur between 9 pm and 6 am and involve more than one vehicle. Also, very few of these crashes were reported to occur in a curve where ADHL would be expected to have the greatest benefits.

It is also notable that a reduction of claims for property damage liability in the range of 5-10% is best translated into a 2.5-5% reduction in overall crashes since there are on the order of two property damage liability claims for crash event that involves two vehicles [2].

Even though the literature may not be conclusive regarding the effect of ADHL, this technology has been included in the rating protocol at the Insurance Institute for Highway Safety (IIHS). This was mainly due to the great potential of avoiding collisions in the dark. It is reported that about half of all fatal crashes in the U.S. occur in the dark, and more than a quarter occur on unlit roads. The rating is based on the reach of a vehicle's headlights as the vehicle travels straight and on curves [5].

So far no previous studies have shown effectiveness figures for specific crash types or situations. The objective of this study was therefore to investigate the real-world benefits of adaptive headlights in different crash types in Sweden.

METHODS

This study used police reported passenger car injury crashes from the Swedish national accident database (Strada). Police records from accidents 2010-2015 including vehicle data for Volvo cars manufactures 2006-2015 were acquired. VIN-numbers were used to identify cars with and without ADHL. In total 1,303 injured drivers in ADHL-fitted cars and 5,262 injured drivers in cars without ADHL were included in the analysis, see Table 1.

Table 1. Number of injured drivers in passenger cars with and without ADHL per year of manufacture.

model year	n, cars with ADHL	n, cars without ADHL
2006	15	1,134
2007	20	1,156
2008	9	981
2009	6	689
2010	70	528
2011	190	492
2012	384	168
2013	297	56
2014	214	45
2015	98	13
Total	1,303	5,262

To compare the risk of being involved in an injury crash with and without ADHL, induced exposure was used. This was done since the true exposure of the included vehicle models was not available. This approach has been used in several real-life benefit estimations [6, 7]. With this method the number of crashes in which ADHL are expected to be effective (sensitive crashes) is divided by the number of crashes where ADHL are expected to have little or no effect (non-sensitive crashes). The basic assumption is that the non-sensitive crashes (in the same way as the sensitive ones) will vary with changes in vehicle miles travelled, driver characteristics, numbers of vehicles on the road, among other factors. However, these non-sensitive crashes should be unaffected by the presence of ADHL. Therefore, they can serve as a proxy for the true exposure [8]. In this study, crashes in darkness were considered as sensitive to ADHL while crashes in daylight was considered to be non-sensitive. Crashes in dusk/dawn or unknown light conditions were excluded from the analysis.

Thus, the effect of ADHL is considered to be zero if R in Equation 1 is equal to 1.

$$R_1 = \frac{A_{ADHL}}{N_{ADHL}} \div \frac{A_{no-ADHL}}{N_{no-ADHL}} \qquad \text{(Equation 1)}$$

A_{ADHL} = number of crashes *sensitive* to ADHL, involving cars *with* ADHL

$A_{no-ADHL}$ = number of crashes *sensitive* to ADHL, involving cars *without* ADHL

N_{ADHL} = number of crashes *non-sensitive* to ADHL, involving cars *with* ADHL

$N_{no-ADHL}$ = number of crashes *non-sensitive* to ADHL, involving cars *without* ADHL

The effectiveness in reducing crashes in relation to non-sensitive crashes was calculated as follows:

$$E_s = 100 \times (1 - R_1)\% \qquad \text{(Equation 2)}$$

The standard deviation of the effectiveness was calculated on the basis of a log odds ratio variance, see below [6].

$$\text{Sd}\,(\ln R_1) = \sqrt{\frac{1}{A_{ADHL}} + \frac{1}{A_{no-ADHL}} + \frac{1}{N_{ADHL}} + \frac{1}{N_{no-ADHL}}} \qquad \text{(Eq. 3)}$$

The 95% confidence limits are given in Equations 4-5.

$$R_{LOWER} = R_1 \times \exp(1{,}96 \times \text{Sd}) \qquad \text{(Equation 4)}$$

$$R_{UPPER} = \frac{R_1}{\exp(1{,}96 \times \text{Sd})} \qquad \text{(Equation 5)}$$

The overall effectiveness was calculated based on all crashes in the sample as well as for different crash types. Single-vehicle crashes, where ADHL would be expected to have benefits due to improved visibility in curves, were compared to head-on and intersection crashes, where ADHL would be expected not to have the benefits compared to cars without ADHL. Collisions with vulnerable road users (VRU) were also included in the comparison.

RESULTS

Out of all passenger car crashes in the sample, 23% occurred in darkness, 65% in daylight and 12% in dusk/dawn or unknown light conditions, see Table 2. Head-on/intersection crash scenarios showed a similar distribution while collisions with VRU had a higher proportion of crashes occurring in dusk/dawn or unknown light conditions. Single-vehicle crashes accounted for the highest proportion of crashes in darkness, 35%.

Table 2. Number of injured drivers in passenger cars in darkness and daylight per crash type.

Crash type	n, darkness	n, daylight	n, dusk/ dawn/ unknown
Single vehicle	262 (35%)	396 (52%)	98 (13%)
Head-on/ intersection	478 (22%)	1,487 (69%)	188 (9%)
Collisions with VRU	276 (22%)	764 (60%)	225 (18%)
All crash types	1,731 (23%)	4,834 (65%)	930 (12%)

The estimated effectiveness of ADHL in reducing crashes in darkness is shown in Table 3 per crash type. No significant reduction of crashes in darkness was found for head-on/intersection crashes or collisions with VRU. For single-vehicle crashes a significant crash reduction of 39% with a lower limit of 11% was found (95% CI). The overall crash reduction had a point estimate of 2%, although not significant.

Table 3. Results of the induced exposure analysis for different crash types.

Crash type	Effectiveness	95% CI lower, upper
Single vehicle	39%	11%, 59%
Head-on/ intersection	3%	-27%, 26%
Collisions with VRU	-9%	-56%, 24%
All crash types	2%	-12%, 15%

Further analysis was performed to ensure the causality between the calculated reductions of injury crashes and the ADHL fitment. As it could be expected, cars with ADHL were fitted with an optional safety package (called Driver Support) to a larger degree than cars without ADHL, see Table 4. This safety package includes a number of technologies such as Lane Departure Warning (LDW) and/or LKA (Lane Keeping Assist), Driver Alert, interurban Autonomous Emergency Braking (AEB), also with pedestrian detection on some models.

The data were stratified into 2 subgroups depending on the fitment of the Driver Support package. The analysis showed no variation from the overall results.

Table 4. Fitment rate of the Driver Support package across the included cars with ADHL and without

	ADHL	no ADHL
Driver Support package	15%	1%
no Driver Support package	85%	99%
Total	100%	100%

DISCUSSION

Many studies have reported increased crash risks associated with driving in darkness [9, 10 and 11]. Some studies also controlled for risk factors such as age, gender and vehicle mileage but very few studies controlled for risk factors especially associated with night-driving such as drink driving, fatigue etc. When Johansson et al. [12] used night-time crashes in daylight as controls to isolate the effect of darkness, no significant risk increase for passenger car crashes was found, neither for urban nor rural areas.

These findings could suggest that the increased risk in night-driving may be more associated with other risk factors then darkness itself, and that drivers in general are able to adjust their driving behaviour to poor visibility conditions.

However, it is not hard to imagine that there are scenarios where better visibility could have facilitated the detection of a risky situation and consequently mitigated the accident risk. IIHS has estimated that better visibility with ADHL could theoretically address 88-91% of crashes in curves at night, which would translate into an overall injury crash decrease of 2-8% dependent on injury severity [2].

The present study presents overall benefits of ADHL within the same range. Moreover the effectiveness in specific crash scenarios was calculated. In passenger car injury crashes involving more than one vehicle or VRUs, no significant risk reduction was found. Regarding collisions with other cars it could be logical that ADHL would not be more beneficial than other modern headlights. The extra visibility given by bending lights in curves would arguably only give a marginal advantage in head-on and intersection scenarios.

Generally there may be a critical factor associated with improved lights, in that driver may use improved visibility to increase their speeds. If better lights are associated with a higher speed profile, the benefits of higher visibility can easily be lost. This question could be the subject for further research in real life or simulator.

For collisions with VRUs the benefit could be expected to be higher than for passenger car collisions. Especially since Johansson et al. [12] showed that pedestrian and bicycle collisions were the only crash type associated with increased risk in darkness. One reason could be that approximately 85% of all VRU collisions occur in urban areas where street lightning is common. However, the material was too small to further investigate this issue.

In the present study, the only significant decrease in injury crash risk was found in single-vehicle crashes in darkness. As ADHL are designed to handle this typical scenario it is reasonable that this was where the benefits were found. However, single-vehicle crashes in darkness only correspond to 3.5% of all passenger car injury crashes which results in a marginal overall effectiveness of ADHL with a point estimate of 2%. Based on these findings, it is thereby doubtful that ADHL should be given great attention in rating schemes and assessment programs.

Data quality may represent a limitation in the calculations made in this study. Police-reported crashes were used, and these are well-known to suffer from a number of quality issues and underreporting. Injury severity measures were based on police assessments, which have been previously shown to have limitations [13]. However, it was assumed that these limitations would equally affect cars with and without ADHL and therefore it was not expected to affect the overall results to any large degree.

Another limitation was that the effectiveness calculation did not control for other risk-factors associated with night-driving. Neither were any controls made for dissimilarities between the cars with and without ADHL. As can be seen in Table 1, ADHL-fitted cars were in general newer than cars without ADHL. Though it would be possible to control for these factors, an induced exposure approach would normally compensate for this, because the effectiveness is given by the relative differences between the cars with and without ADHL. However, it could be argued that ADHL-fitted cars could gain benefits from other optional support systems (Driver Support package). Especially in night time driving as they address some of the risk factors associated with darkness such as fatigue or impaired driving.

To control for this potential bias additional benefit calculations were made excluding cars with driver support systems. As the effectiveness of ADHL on single-vehicle crashes did not change significantly, it was concluded that the dissimilarities between the case and control vehicles would not influence the result to any large degree.

A key component in the benefit estimation was to identify ADHL fitment by using VINs. Sternlund et al. [14] has previously used the same method to consult electronic parts catalogues. Fitment assessment using VIN may be even more important in the future as more and more optional vehicle safety systems are introduced.

CONCLUSIONS

Based on Swedish police records, Adaptive Head Lights (ADHL) were found to significantly reduce single-vehicle passenger car injury crashes in darkness by 39% (95% CI lower limit 11%). No significant crash reductions were found in other crash types.

The overall benefit of ADHL in risk reduction was estimated to be approximately 2%. Based on these findings, it may be doubtful that ADHL should be given great attention in rating schemes and assessment programs.

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