Effects of seat belt load limiters on driver fatalities in frontal crashes of passenger cars

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Several studies have shown that belts can contribute to thoracic injuries in certain loading conditions, especially among older occupants.

Patents filed in the 1950s and 1960s described methods of limiting belt loads.

Due to the increased excursion associated with load limiting devices, few were used before frontal airbags became standard.

Today, load limiting belts are a *de facto* standard.
Seatbelt load limiters became widespread in late 1990s

IIHS-tested models with seatbelt load limiters
Cadaver testing, field studies show chest injury reduction capability of load limiters

- Cadaver testing: Kallieris (1995), Crandall (1997), Kent (2001) and others have shown reductions in rib fractures when limiting belt loads.

- Field studies: Renault and Peugeot vehicles with various belt loads investigated in a series of French studies.

Injury risk curves from Foret-Bruno et al. (2001)
Load limiters have improved NCAP scores

- 14 structurally unchanged models have been retested in NCAP after load limiters were installed (and no crash tensioners added)
  - 1 received one less passenger star (no driver stars reduced)
  - 4 had unchanged star ratings for both occupants
  - 9 improved by at least one star for one or both occupants
Have airbags been shown to eliminate risk of injury from increased excursion?

- Cadaver studies usually have not investigated head injury risk, though Crandall et al. observed a 42% increase in head excursion with 2 kN load limiters and no airbags.

- Peugeot/Renault field studies did not discuss head injury risk.

- NCAP full-width configuration may reduce observations of head contact risk:
  - Minimizes: vehicle rotation, duration of loading phase, oblique airbag loading
  - Maximizes: clearances within occupant compartment (less intrusion), initial restraint system stiffness
Ideal airbag protection often has been assumed

“The dilemma of using a shoulder belt force limiter… is selecting a limit load that will balance the reduced risk of significant thoracic injury…against the increased risk of significant head injury due to the greater upper torso motion allowed by the shoulder belt load limiter. However, with the use of air bags, this dilemma is more manageable since it only occurs for non-deploy accidents where the risk of significant head injury is low even for the unbelted occupant.”

Mertz et al. 1995
Ideal airbag protection often has been assumed

“The lowering of the shoulder belt load allows the thoracic injury risk to be reduced. At the same time, the airbag avoids the increase of the head and neck injury risks due to greater torso motion.”

Petitjean et al. 2003
Load limiters in IIHS offset frontal tests

- 139 sedans with “Good” or “Acceptable” structure
  - Without load limiters: 20 tests, 4 contacted steering wheel through airbag (20%)
  - With load limiters: 119 tests, 68 bottomed AB (57%)
- With a few exceptions, resulting steering wheel contact did not cause a large head acceleration, but in about two-thirds of the “bottomed AB” cases it was the highest acceleration in the entire test
- The vehicles have other restraint differences: many without load limiters did not have “depowered” airbags
Since load limiters introduced, increasing amounts of belt spool-out and frequency of steering wheel contact

Sedans with Good or Acceptable Structural Ratings

- Steering wheel contact
- No steering wheel contact
- MY Average

Since load limiters introduced, increasing amounts of belt spool-out and frequency of steering wheel contact.
Sample ODB performance of various load thresholds

<table>
<thead>
<tr>
<th></th>
<th>2003 Honda Accord</th>
<th>2004 Mazda3</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 cm</td>
<td>Belt spool-out</td>
<td>40 cm</td>
</tr>
<tr>
<td>4.5 kN</td>
<td>Apparent load threshold</td>
<td>3 kN</td>
</tr>
<tr>
<td>291</td>
<td>HIC</td>
<td>198</td>
</tr>
<tr>
<td>42 g</td>
<td>Chest acceleration</td>
<td>37 g</td>
</tr>
<tr>
<td>32 mm</td>
<td>Chest deflection</td>
<td>28 mm</td>
</tr>
</tbody>
</table>
Examples of steering wheel contact through AB

2003 Mercedes E500

2004 Kia Spectra
Summary: Pros and cons of seatbelt load limiters

- **Potential benefits of belt load limiters**
  - Increased ride-down if safety cage stays intact
  - Narrowly concentrated shoulder belt loads are limited
  - Better load sharing with force-distributing airbag

- **Potential problems with belt load limiters**
  - May over rely upon airbag protection, which may not be adequate under certain crash conditions
  - Increased ride-down raises risk of hard contact with steering wheel and other components, especially with intrusion
  - Lack of occupant restraint during rebound and in secondary impacts
What is the overall effect of load limiters in real-world crashes?

- Identified passenger cars that had load limiting seat belts added to their designs without structural changes, advanced airbag features, ESC
- Because airbag “depowering” occurred during similar years as load limiter installations, this restraint change was tracked as well
- Only one model received pretensioners in the absence of structural design changes
Study methods

- Used FARS with Polk registration database to calculate fatality rates of belted drivers in 12 o’clock frontal crashes of the same vehicles before and after LLs were added or airbags depowered.

- To account for calendar year and age effects, control groups were developed for each model.
  - Control groups consisted of models that did not make restraint system changes over the same model and calendar years as the study vehicles.
  - Study vehicle fatality rates were adjusted based on the rates of the control groups.
Four fatality rate analyses conducted
Various combinations of belt technology and depowered airbags

<table>
<thead>
<tr>
<th>Pre-change technology</th>
<th>Post-change technology</th>
<th>Control group restraint changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neither</td>
<td>Load limiters</td>
<td>None</td>
</tr>
<tr>
<td>Neither</td>
<td>Load limiters, depowered airbags</td>
<td>Airbags depowered</td>
</tr>
<tr>
<td>Depowered airbag</td>
<td>Load limiters, depowered airbags</td>
<td>None</td>
</tr>
<tr>
<td>Neither</td>
<td>Load limiters, depowered airbags, pretensioner</td>
<td>Airbags depowered</td>
</tr>
</tbody>
</table>
## Results

<table>
<thead>
<tr>
<th>Load limiter and/or depowered AB?</th>
<th>Pre-change</th>
<th>Post-change</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reg. Vehicle Years</td>
<td>Driver deaths</td>
</tr>
<tr>
<td>Neither</td>
<td>Load limiter</td>
<td>765,309</td>
<td>12</td>
</tr>
<tr>
<td>Neither</td>
<td>Both</td>
<td>8,825,779</td>
<td>126</td>
</tr>
<tr>
<td>Depowered AB</td>
<td>Load limiter</td>
<td>6,069,741</td>
<td>91</td>
</tr>
<tr>
<td>Neither</td>
<td>Both + pre-tensioner</td>
<td>1,410,719</td>
<td>14</td>
</tr>
</tbody>
</table>
Variation in results may be related to variation in restraint system changes

NCAP belt loads may help quantify this variation

- Different amounts of load limiting were used in different vehicles
- Frontal airbags were depowered by varying degrees
- Many vehicles have been tested in NCAP with force transducers attached to the shoulder belt webbing
  - Allows comparison of load sharing between belt and airbag
**NCAP belt loads for study vehicles**

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Shoulder belt loads by presence of depowered airbags and belt load limiters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Neither</td>
</tr>
<tr>
<td>Chevrolet Cavalier (four-door)</td>
<td>6.7</td>
</tr>
<tr>
<td>Dodge Stratus</td>
<td>8.2</td>
</tr>
<tr>
<td>Honda Civic (four-door)</td>
<td>8.1</td>
</tr>
<tr>
<td>Pontiac Grand Prix / Oldsmobile Intrigue</td>
<td>8.6</td>
</tr>
<tr>
<td>Saturn SL</td>
<td>5.4</td>
</tr>
<tr>
<td>Toyota Camry</td>
<td>6.3</td>
</tr>
</tbody>
</table>

*In addition to depowered airbags and load limiters, crash tensioners were also added to the Camry restraint system.

- All belt forces decreased with load limiter except for Cavalier
  - Same vehicle demonstrating decreased fatality rate associated with load limiter installation (0.82 rate ratio)
  - Suggests some other unknown change, possibly to airbag or extent of load limiting
Decreasing NCAP belt loads associated with increased fatality rates
Potential problems with overdependence on airbags in frontal crashes

- Airbag deployment algorithms cannot be ideal for every crash scenario
- Airbags can only restrain occupants for the initial event of potentially multiple-event crashes
- Airbags can only restrain occupants for the forward-loading phase of an event, not during rebound
- Airbag efficacy decreases with offset or oblique crash loads and with intrusion
Airbag limitations: slight impact variations can affect deployment characteristic

Vehicles requiring retests due to non-ideal frontal airbag deployment in offset test:

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>Deploy time</th>
<th>Belt spool-out</th>
<th>Head contact</th>
<th>HIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>18 ms</td>
<td>31 cm</td>
<td>124 g</td>
<td>1160</td>
</tr>
<tr>
<td>B</td>
<td>46 ms</td>
<td>25 cm</td>
<td>70 g</td>
<td>363</td>
</tr>
</tbody>
</table>

- Cadillac CTS
- Honda Pilot
- Infiniti FX35
- Kia Spectra
- Nissan Altima
- Honda Fit
- Hyundai Elantra
- Jeep Liberty
- Lincoln Town Car
- Volkswagen New Beetle
NASS cases suggest excursion injuries, even with airbag deployment
Countermeasures with potential to reduce belt-induced injuries while balancing excursion risks

- 4- or 5-point belts
- Inflatable belts
- Occupant-specific restraint characteristics (e.g. bone scanning cited by Hardy, et al. 2005)
  - Foret-Bruno et al. risk curves show 4kN belt load produces thoracic injury risks of:
    - 70% for 80 year olds
    - 30% for 70 year olds
    - <10% for ≤ 60 year olds
Limitations of the study

- Cause of death is not known from FARS
  - Reliable data of injury by body region are not available on the make-model level so actual injury mechanisms aren’t known
- General scarcity of data
  - Limited number of vehicles met the restraint and structural requirements
  - Resulting confidence intervals wider than desired
- Only one model with pretensioners could be studied
Strengths of the study

- Unique chance to look at a commonly used restraint technology in isolation
  - Today, all new vehicles have load limiters so “pre-change” fatality rates won’t be available
  - Future restraint changes more likely to be accompanied by structural redesigns
- Evaluation of technology under the variety of conditions found in field crashes
  - Laboratory component tests and unique crash test configurations offer a more limited evaluation
Conclusions

- Available data suggest load limiting belts are not reducing the risk of fatality, and may be contributing to an increased risk in some vehicles.
- Shifting load sharing too far from the belt to the airbag can be problematic.
- The potential injury-causing risks associated with excursion from load limiting belts cannot be ignored and must be balanced with the potential benefits.
- “Tuning” the restraint system for ideal performance in any single crash test may not produce the most effective systems for the wide range of real-world crash scenarios.
Insurance Institute for Highway Safety — Vehicle Research Center, Ruckersville, Virginia