BACKING ACCELERATION AND RESPONSE TIME TO AN AUDIBLE WARNING IN A FIELD TEST

Jeffrey W. Muttart
Human Performance Laboratory
University of Massachusetts - Amherst
muttart@gmail.com
http://www.ecs.umass.edu/hpl/

David Hurwitz
Assistant Professor
Oregon State Univeristy
David.hurwitz@oregonstate.edu
http://cce.oregonstate.edu/people/faculty/hurwitz.html

Anuj Kumar Pradhan
Division of Epidemiology, Statistics and Prevention Research
NICHD, National Institutes of Health
pradhanak@mail.nih.gov
http://www.nichd.nih.gov/about/staff/bio.cfm?nih_id=0014399479

Donald L. Fisher
Human Performance Laboratory
University of Massachusetts - Amherst
fisher@ecs.umass.edu

Michael Knodler
Department of Civil and Environmental Engineering
University of Massachusetts Amherst
Mikeknod@aol.com
http://www.ecs.umass.edu/index.pl?id=3913

Telephone: 1 – 860 – 912-2280

DATE – 8 March 2018

5962 words + 6 figures = 7462 words

ABSTRACT

Young children are over-represented in run-over backing crashes. Our goal was to propose a supplemental backing safety system that is based in part upon the way drivers behave when backing. Inherent in the backing collision avoidance model is the need to understand how drivers accelerate when backing and how drivers' respond. To develop a backing safety system that will supplement the abilities of a driver, driver's response times and backing acceleration were recorded in a field experiment. The results show that backing acceleration varies predictably while backing and that the backing profile may be modeled with cubic function for short and long backing maneuvers. Additionally, driver response times were much longer than typical response times associated with forward hazards. Drivers exhibited confusion as evidenced by a rather large variance in response times. On the basis of the findings, optimal detection ranges are offered that could be used to help design a collision warning system when backing.

INTRODUCTION

Young children are over-represented in backing crashes (1). Part of the recent problem is the increase in high profile vehicles such as SUVs and mini-vans that provide little rearward view (1). As a means of addressing backing safety, drivers' responses and backing accelerations were recorded in a field experiment. The purpose of the experiments is to gain information for the development of a collision warning system when backing.

The crash statistics show that there is a problem involving high profile vehicles backing over stationary young children. Children under the age of five who were struck by a vehicle were more likely to die in a non-traffic related collision than a traffic related collision (2). The CDC reported that in the years 2001 to 2003, 40 percent of the injuries to children occurred in a driveway or a parking lot (3). In a six year review of pediatric pedestrian injuries, 80 percent of pedestrians struck while in a driveway were under the age of five (4). Two other studies reported the average age of children in reversing and driveway crashes to be two years of age or less (5, 6). The Utah Department of Health (1) reported that half of driveway deaths involved children age one to two years and 19 of 20 driveways deaths between 1997 and 2003 involved a high profile vehicle. Utah's Department of Health's findings were similar to those of Brison, Wicklund, and Mueller (7) who found that fatalities for children younger than five tended to occur when the child was backed over in the home driveway by the family van or light truck driven by a parent. This research is an attempt to address this problem.

The primary goal of any transportation safety related research should be to improve crash avoidability. A warning distance [WD] or distance at which a warning is initiated, is a critical issue in that too large a distance leads to nuisance warnings and too small a distance leads to inadequate times to avoid a crash. Therefore, a collision avoidance system may be optimized by modifying the area monitored by the system based upon the speed and acceleration of the vehicle.

On the basis of the literature cited earlier, the crash scenario that is of greatest concern involves vehicles backing over small stationary children in driveways. Therefore, slowing a vehicle is not sufficient to avoid a crash, the driver must be able to appreciate the problem and bring the vehicle to a complete stop. Hence, the length of the warning distance should be based upon the total stopping distance (braking distance - BD), the velocity of the vehicle (V) and the time components. There are three time components that must be addressed, hazard detection/warning system latency (T_{SL}), the braking response time of the driver (T_{RT}) and braking (vehicle) latency (T_{BL}). System latency (T_{SL}) includes the time for the system to find the object, recognize the object as a hazard and warn the driver. Brake response time (T_{RT}) is from the onset of the warning to brake application. Braking latency (T_{BL}) is defined as the time from brake application to measurable deceleration. The warning distance should be at least as large as the total stopping distance of the average driver with consideration given to minimizing nuisance warnings and maximizing proper warnings. The total stopping distance is the sum of the response distance and the stopping distance.

$$Total\ Stopping\ Distance = Response\ distance + Stopping\ distance \qquad (1)$$

Response distance is the distance traveled during the driver's response. Response distance is based upon the velocity of the vehicle and the sum of all time components involved in the response. In the case of a warning system, the time components include system latency, driver brake reaction time and a braking latency. Furthermore, we must also account for acceleration or deceleration during the response phase. If the system was to assume a constant speed and the vehicle was accelerating, the system would underestimate the distance closed by the vehicle. For this reason, a system must anticipate the future speed of the vehicle, not the current speed.

$$Response\ distance = \left(V_o \times \sum_{i=1}^{n} t_i\right) \pm \left(\frac{1}{2} \times g \times f \times \sum_{i=1}^{n} t_i^2\right) \qquad (2)$$

V_o is the original velocity when the hazard is detected by the sensor. t_i represents one of the time components that are summed (system latency, brake response time and braking latency). g*f refers to the anticipated acceleration of the vehicle during the response phase (measured in ft/s^2). f is the average acceleration factor (in gs) from the speed when the obstacle is detected by the system to anticipated peak speed on the basis of the polynomial function derived from this research. If accelerating when backing and the system discerns the peak speed that the vehicle will attain (given the range at detection). If there is sufficient distance to accelerate to a speed greater than average peak speed, the final velocity was be assumed to be the average peak velocity.

The stopping distance must be calculated with an assumption that the vehicle will be traveling a final velocity (V_f). The warning distance will be a function of the vehicle speed, the acceleration of the vehicle at the time of the detection of the obstacle and the range at which the obstacle is detected. For instance, if a vehicle is traveling a speed that would suggest the driver was engaged in a long backing maneuver, and the vehicle is still accelerating (gaining speed) the system will assume the vehicle will reach a peak speed. The avoidance algorithm will calculate the warning on the basis of what it believes the speed of the vehicle will be rather than the current speed. On the basis of the range at detection of an obstacle, the system will assume the peak speed will be the minimum of the average peak speed of a long backer (or short backer if traveling slowly) or the peak speed that the vehicle will attain given the range, speed and acceleration of the vehicle at detection of an obstacle.

$$V_f^2 = MIN\left(V_{peak}^2, V_o^2 \pm 2 \times g \times f \times D\right) \tag{3}$$

After projecting the final velocity, the system will calculate the distance necessary to stop if traveling the projected final speed. If the vehicle is decelerating when detection occurs a minus (-) would replace the plus or minus. If decelerating, the final speed would be less and the situation would be less severe than if the vehicle was accelerating. The stopping distance is a dependent upon the speed of the vehicle and the deceleration of the vehicle. Driver deceleration does not vary significantly when faced with an emergency response scenario. However, the available literature has reported deceleration behavior of drivers who have faced both emergency and non-emergency response scenarios.

Llaneras et al (8) reported decelerations of 0.29 and 0.27 gs, which are associated with routine negative acceleration rates when slowing for a stop sign or traffic signal (9). Llaneras et al measured decelerations when responding to a hazard in which the drivers typically did not get closer than 2 m after a response. The current warning system did not offer a warning until a driver closed within 2 m of the obstacle before a response. Llaneras et al also noted that deceleration increased when drivers received a later, more urgent, warning. Typical deceleration in an emergency response approaches 0.6 to 0.8 gs (10). For the purpose of this model, we are interested in the distance a driver will need to avoid if responding with a hard brake, which we will assume to be 0.5 Gs (4.9 m/s^2), which is based upon the research by Warner et al (10), while giving consideration to the results by Llaneras et al.

$$Stopping\ distance = \frac{V_f^2}{2 \times A} \tag{4}$$

V_f is the velocity at the end of the response phase given the acceleration (positive or negative) of the vehicle from the time of the hazard detection until the start of the driver's maneuver. A is the deceleration of a vehicle during braking [0.5 gs (4.9 m/s^2)].

The warning distance must be greater than the total stopping distance because it does not suffice to stop at impact (on a small child). A warning should be given immediately if the range at which the obstacle is detected is shorter than the total stopping distance (or the response distance or the stopping distance).

$$Warning\ distance\ > \ Min\ (R\ , Total\ stopping\ distance) \tag{5}$$

R is the range (distance) detected by the sensing system between the vehicle and obstacle.

If the velocity is closer to peak speed, the average acceleration will be less than if the speed at detection is near zero. Again, the system will assume that the driver will reach peak speed for the particular backing maneuver. The system must discriminate as early as possible higher backing acceleration typical of long backing scenarios from slower backing accelerations typical with short backing scenarios.

$$f(V^{\pm}) = \begin{cases} \dfrac{V_{peak} - V_o}{t} & A^{+} \\ \dfrac{V_o}{t} & Otherwise \end{cases} \qquad (6)$$

The polynomial between the peak velocity minus the current velocity (V_o) with +/- depending on acceleration or deceleration. The polynomial is a function that we will fit to the backing data in order to determine the time that it takes the driver to reach the peak speed. It is described in more detail below. The units used in the calculation are as follows: Warning distance (WD) will be reported in feet; Velocity or V (ft/s); Time of the system latency or T_{SL} (s); Perception-Reaction Time or T_{RT} (s); Braking latency or T_{BL} (s) and Braking Distance (Ft). A deceleration of 0.5 Gs was selected, which is typical of a relatively wet road friction.

There are two backing scenarios in the current experiment, short backing (approximately 5 m) and long backing scenarios (approximately 15 m), representing different situations in which a driver might be backing. The information that must be gained in this research is response time, braking latency, acceleration profiles for short versus long backers, as well as peak speed for short and long backers. On the basis of this research and the kinematic calculations, an optimal system detection area will be suggested. The system detection area will be based on both total stopping distance as well as the limitations of the view to the rear of the vehicle. As stated earlier, the goal of this research is to propose a supplemental system. By supplemental we are referring to a system that improves a driver's performance but does not replace the driver and a system that aids improves the performance of a driver in a high profile vehicle who may have a restricted view to the rear.

Views to the Rear

A warning system should monitor at least the distance that is obscured by the high profile vehicles. Compared to standard sedans, SUVs and minivans offer a restricted view to the rear due to their higher profile which creates a larger obscured area immediately behind the vehicle that cannot be accessed by direct observations or mirrors (See Figure 1). The blind spot is defined as the distance between the back of the vehicle and a cone that is 0.6 m (2 ft) high (roughly the height of a young child). After measuring several vehicles types, Paine and Henderson (11) indicated that a 0.6 m object could not be seen any closer than 4.5 m to 9 m (15 to 30 ft) from the rear of most station wagons and SUVs measured. Consumer reports (12) measured the blind spots to several vehicles types and reported the average blind spot for a sedan to be 3 to 10.7 m, (10 to 35 ft) while SUVs and pickups had an average blind spot of up to 15.2 m (50 ft).

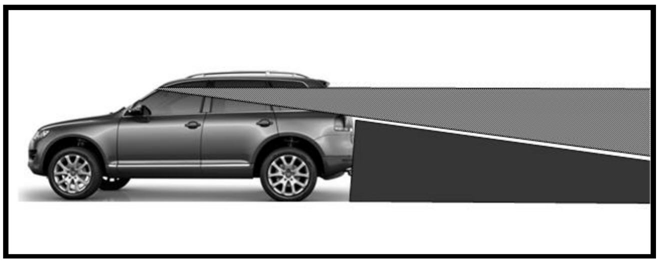

Figure 1. The cone of visibility and obscured (darker) areas behind a high profile vehicle.

Warning System Latency and Sampling Period [T_{SL}]

Warning latency should not be confused with braking latency. Warning latency refers to the time necessary for the warning system to sample the movements of the subject vehicle as well as objects in the environment and offer a warning to the driver (if necessary). Eberhard, Moffa, Young, and Allen (13) estimated the latency for the warning system to be 0.2 seconds.

Glazduri (14) measured the response of several backing sensor systems and reported warning delays with a range from .08 to .23 seconds. He also reported that all response times were within the ISO recommended limit for low-speed sensor systems of 0.35 seconds.

A warning system must be constantly sampling the environment and subject vehicle kinematics. With any sampling system, too narrow a sampling window could increase the probability of anomalous readings (and nuisance alarms) and too large a sampling window (too much filtering) slows the system and decreases its efficiency. On the basis of the two studies mentioned, a sampling window of 0.2 seconds would represent a reasonable although conservative sampling period.

Vehicle (Braking) latency [T_{BL}]

Several studies have shown that the variability within the braking latency phase of the driver's response is influenced by driver cognition. One may expect drivers to brake with similar force and speed regardless of the complexity of the cognitive portion of a response. However, drivers responding to a known stimulus push the brake pedal faster and ultimately had a higher deceleration than did drivers who were responding to road hazards. There have been three types of studies in this regard: those that measured braking latency using a light stimulus (15, 16, 17, 18); those who measured response latency when responding to a road hazard (19, 20, 21, 22, 23) and an experiment that measured braking latency when responding to a road hazard and engaged in a cell phone task (23). The literature shows that braking latencies increase as the cognitive portion of the response increases. A backing warning may be a low probability event and may require a driver to respond at a time he or she does not see the hazard. Low probability events and unknown hazards both create a more complex response scenario. The vehicle latencies in the related research report times from 0.1 second when responding to a light going on to near 0.25 seconds when responding to a road hazard and near 0.4 seconds when engaged in a cell phone task. Drivers responding to a backing warning would be expected to experience vehicle latencies near 0.25 seconds.

Hypotheses

The variables that will be addressed by the current research include backing acceleration for both short and long backers as well as brake reaction time (T_{RT}). Based upon the existing research to date and the formulated problem statement, the current research effort evaluated four hypotheses.

1. The average acceleration will be less when backing a short distance than when backing a long distance and the profile of short and long backers will differ.
2. Drivers will react slower if offered a warning shortly after starting to back as opposed to sometime during a longer backing due to the larger number of cognitive demands during the initial portion of the backing process (looking to the left and right, putting the car into gear, releasing the brake and depressing the accelerator).
3. As response times get longer, braking latency will increase as well. Braking time will be recorded from brake application to peak brake displacement (recorded by a string potentiometer.
4. Drivers will need greater than the current 2 m system detection area to avoid most crash scenarios when backing.

METHODOLOGY

This study sought to acquire relevant information necessary to develop a backing warning system. The required information included measurement and determination of where the driver was fixating (reported in a separate paper (24)), backing acceleration profiles for short and long backing maneuvers, reaction time to an audible warning, and crash avoidance probabilities.

Participants

Thirty-six drivers were recruited through a variety of mediums in the greater Amherst and Northampton, Massachusetts area including the UMass Amherst campus. Participants included 28 males and 8 females with an average age of 27.6 years and 9.3 years of driving experience. All participants were required to have a valid driver's license.

Equipment

A 2007 Volkswagen Touareg with a combined rear view camera and sonar sensor was used (See Figure 2). The Touareg was equipped with four rear sensors to detect objects behind the vehicle. The ultrasonic waves operated at four hertz. There were warning lights on the roof at the center of the interior of the vehicle at both the front and back of the vehicle. The warning lights showed green, amber when within six feet of an obstacle and red when within two feet of the obstacle. The audible warning sounded beeps to indicate an obstacle is behind and the vehicle moved closer to an object the beep frequency increases. At at approximately one foot distance, the beep became continuous.

A Vericom 3000 accelerometer was mounted to the windshield and collected vehicle speed, engine speed and throttle percent from the vehicles on board diagnostic port (OBD II). The Vericom separately recorded vehicle speed, tri-axle accelerations and brake pedal displacement.

A padded piece of plywood on a hinge the size of a 50th percentile four-year-old was used as a surrogate for a child behind the vehicle. The other safety constraint involved the use of tarpaulin stretched over saw horses on top of the tables in place of parked vehicles. The experiment was conducted on a closed portion of the football stadium parking lot.

A hinged flap was attached to the sensor at the rear bumper of the vehicle and could be activated by pulling a string that was attached to a string potentiometer. A pull of the potentiometer was recorded by the Vericom and an identifying mark was placed on the data. The Vericom recorded at 100 Hz, while the OBD II (vehicle on-board computer) data was recorded at 7 Hz.

Figure 2 The interior of the test vehicle with rear camera view in the center console.

Procedure

An experimental assistant familiarized each driver with the features of the vehicle. These features included the proximity warning and the rearview (backing) camera. All participants completed 16 trials, each of which included a series of parking maneuvers. The trials took place over two days (eight trials per day) occurring no more than 10 days apart. Three unexpected crash scenarios were introduced during trial 7 of day 1 and trial 3 and 7 of day two. Each driver performed 10 to 12 short backing maneuvers and 10 or 11 long backing maneuvers. The short backing scenarios were designed to be similar to backing out a parking space. In the short backing scenarios, the drivers backed approximately five meters (16.5 ft.) back and to their left. The long backing scenario was designed to replicate backing on a long straight driveway and each driver backed approximately 15 meters (50 ft.).

Drivers were allowed to familiarize themselves with the vehicle during the first four backing scenarios. These backing maneuvers consisted of two short and two long backing maneuvers. The four rehearsal backing maneuvers occurred within the first two blocks of the ten blocks driven by each participant. After the initial four backing scenarios, drivers were exposed to a braking response event based upon a counterbalanced design so that each event was equally likely to occur on the first or second day of testing and early or late in the testing. Once during the long backing and once during short backing, a warning senor was activated by the experimental assistant. The sensor system on the rear bumper of the vehicle was remotely activated by the researcher without the knowledge of the driver (no obstacle was present). Once during a short backing maneuver the surrogate child pedestrian was surreptitiously place behind the vehicle. The surrogate pedestrian object was visible in the rear-view camera display and would activate the sensor system.

The dependant measures were acceleration, brake response time (T_{RT}) and braking latency (T_{BL}). For the purpose of this research, braking latency is defined as the time from brake onset to peak brake pedal displacement as measured with a string potentiometer. Acceleration was measured from the point the foot began to lift from the brake up to the desired backing distance. Brake response time was measured from the onset of the warning to the point the brake was applied. The manner in which acceleration influences a warning is discussed in the Implementation section of this paper.

RESULTS

Brake Response Time (T_{RT})

There were 35 instances involving the drivers responding to the surrogate pedestrian. In no instance was a measurable response obtained. There were instances when the driver responded but it was at or after impact. In eight instances, the driver recognized the pedestrian and did not back, once the driver did not look into the rear view camera. In the other 27 instances the drivers struck the surrogate pedestrian and only once did a driver look into the rear camera view and strike the pedestrian.

The drivers responding to the intentionally activated false alarm responded rather slowly and the responses had a much larger variance than is typical of forward response times (weighted average M = 2.6; SD = 1.51 sec). Of the 72 false warning response time events, drivers failed to respond 27 times and the event did not transpire 14 times. On six occasions the driver was already on the brake or on the brake within 0.2 seconds of onset when the audible warning was given. The other eight instances involved situations in which the string was not properly pulled or the warning did not occur due to equipment failure.

Drivers who were backing a long distance responded slower than those who were backing a short distance. Using the Wilcoxon Signed Rank Test for non-parametric distributions, the brake reaction times for the short and long backers were compared. Average brake reaction time of the short backers was 2.09 seconds (SD = 1.52 seconds) and the average response time for the long backers was 2.88 seconds (SD = 1.47 seconds). The difference in response times for short and long backing was significant based upon negative ranks [Z (31) = -2.676; p = 0.007]. If we square the standard deviations, we can see that an assumption of a Poisson distribution (the variance equals the mean) would very closely model the distribution of backing response times.

Whenever evaluating a driver’s response time, we must also consider the percent who did or did not respond. In the current experiment, short backers responded 11 of 34 times (32 percent), while long backers responded 20 of 35 times (57 percent).

Time to Peak Brake Pedal Displacement: Braking latency (T_{BL})

Braking latency time is the time from brake onset until peak brake displacement. Generally, drivers backing longer distances depressed the brakes slower than did drivers who were backing a short distance. Although informative, time to peak braking did not reach statistical significance with a Wilcoxon Signed Rank test [Z (31) = -1.305, p = 0.192]. Short backers took an average of 1.15 seconds (N = 11; SD = 0.98) to reach peak pedal displacement and long backers took 1.69 seconds (N = 25; SD = 1.62). As noted earlier, many more short backers did not respond at all.

Peak Speed (V_{max})

Peak speed was determined by finding the point on the velocity versus time graph at which the change in the velocity over the change in time reached an asymptote over a 0.2 second sample ($\partial v/\partial t = 0$). For example, if the scalar speeds over a 0.2 second period decreased (or negative velocity vector increased) or remained constant, then the speed at that point was reported. The time of 0.2 seconds was selected to assure the peak was not due to an anomaly in the results or a slight hesitation in the acceleration. In a few instances, the speed decreased followed by a subsequent increase. Therefore, drivers may reach a higher speed when backing, but they would do so only after a longer period of backing that would likely exceed the backing distance examined in this research.

Drivers who backed a short distance reached an average peak speed of 2.68 mph (SD = 1.246), while those backing a longer distance reached an average peak speed of 6.17 mph (SD = 1.765). The overall average peak speed was 4.6 mph. These results were very similar to those of Harpster, Huey and Lerner (23, p. 895) who stated that "except for extended backing maneuvers maximum backing speeds averaged around 4.8 km/h (3 mph), and did not exceed 11.3 km/h (7 mph)." (See Figure 4)

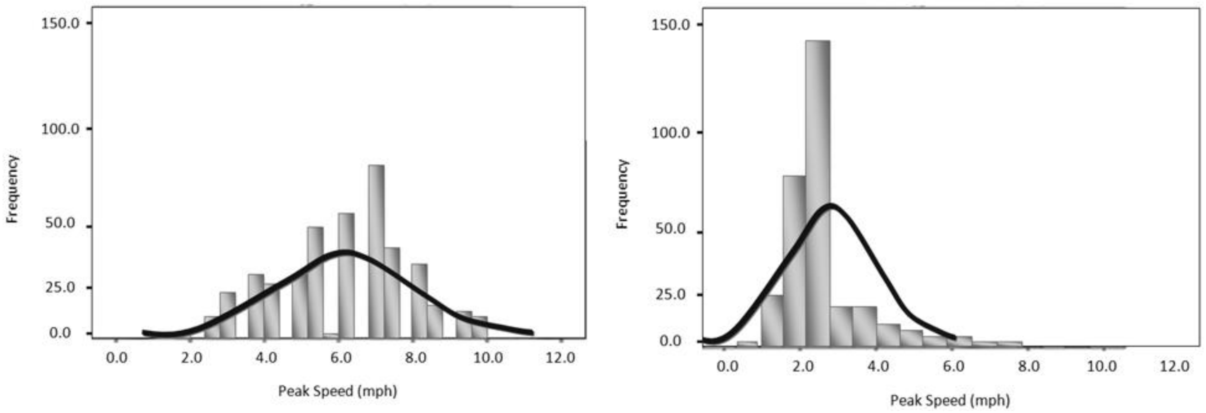

Figure 4 Distribution of peak speeds during long backing (left) and short backing (right).

Backing Acceleration

There were 316 short backing scenarios in which data was collected (some data was lost due to equipment failure, experimenter error and instances where the driver chose not to back due to the obstacle). In 207 short backing instances, drivers reached a speed of 2 mph and only in 39 instances did drivers reach a speed of 4 mph. Similarly, there were 393 long backing scenarios where data was collected, 389 reached 2 mph, 340 had a peak in excess of 4 mph, 236 reached 6 mph and 64 had a peak speed in excess of 8 mph. The average acceleration factor for short backing was compared to long backing using a Mann-Whitney U comparison. The average acceleration for each driver was calculated based upon the peak speed and the time to reach that speed (V/t). Those who back a longer distance did so at a significantly greater acceleration with 704 of 705 long backers having higher accelerations than short backers. [$Z = 17.585$; $p = 0.000$]. Average acceleration factors were 0.03 Gs at 1 mph, 0.05 at 2 mph, approximately 0.075 at 4 mph to peak speed, and then dropped off to 0.02 Gs in the second after reaching peak speed.

These findings were consistent with the results of Harpster, Huey and Lerner (25) who found that drivers typically traveled only 0.91 m (1 ft) in the first second of backing. Also, drivers normally traveled less than 2.44 m (8 ft) after two seconds, which is an average acceleration of 0.076 Gs. Harpster et al.'s findings were also consistent with the findings by Williams (26) and minimally higher than the results from this experiment.

Velocity based acceleration profiles were beneficial for two reasons. First, velocity is direct information from the vehicle, not a calculated figure as is distance. Secondly, velocity based acceleration profiles offer earlier differentiation between short and long backers. Average peak speed for short backers was 2.68 mph. Hence we know a vehicle traveling faster than 2.68 mph is most likely following the long backing profile and will likely reach a peak speed near 6.2 mph. However, much earlier, we can see that a driver backing at 0.06 Gs over the previous 0.2 second is most likely intending to back a longer distance and attain a peak speed near 9 ft/sec. SPSS software regression (trend) analyses were used to determine that a cubic function best modeled the velocity by acceleration profiles seen in Figure 5 and Table 1.

The anticipated acceleration of the vehicle will be based upon the integral of the acceleration profile from the current speed to the minimum of the current speed or peak speed.

$$\int_{Vo}^{Vpeak} \frac{f(V)}{\Delta V} \qquad (7)$$

$$A = f(V) = a_3 \times V^3 + a_2 \times V^2 + a_1 \times V + a_0 \qquad (8)$$

Table 1 Coefficiemnts applied to equation (8) for short and long backing acceleration functions.

Backing Distance	a_3 [m^{-2}]	a_2 [m^{-1}]	a_1 [-]	a_0 [m]
Short	0.002	-0.022	0.064	0.003
Long	0.002	-0.032	0.128	0.003

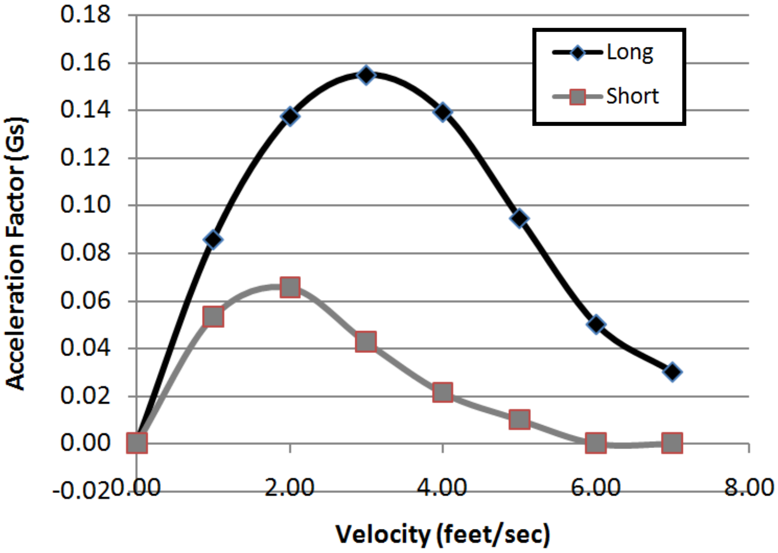

Figure 5 Velocity by acceleration factor profiles for all short (n = 316) and long backers (n = 393).

DISCUSSION

Alarmingly, more than half the drivers in the current study failed to respond. Participants claiming that they did not hear the warning or did not appreciate the purpose of the warning were the most common explanations for failing to respond. Some of those who did not respond failed to discern the warning; some did not have time to implement a response. While there is a need to examine the need for effective warning sounds, we believe a more efficient algorithm that accounts for the drivers' response times, backing acceleration profiles and peak speeds would allow for an earlier warning and fewer nuisance warnings and therefore more respect and attention to the warning.

Drivers backing a short distance responded faster than long backers and reached maximum displacement of the brake pedal earlier than long backers. On the other hand, there appeared to be a speed/accuracy trade off effect. Response times and braking time decreased for short backers but the probability of responding was much smaller and the coefficient of variation (SD/Mean) was more than 20% greater than long backing responses. Speed/accuracy trade-off results are typical of a responder who is over burdened (at the far right of the Yerkes-Dodson, stress versus performance curve (27)). This result may be due to anchoring effects or a refractory period (a response inertia). During a short backing scenario the warning was offered relatively close in time to the moment the driver moves his foot from the brake to the accelerator pedal (much closer in time than the long backing scenario). To return the foot back to the brake may require additional mental workload and is an area that could be explored further.

When comparing the results from Williams (26) with the current results, 0.07 Gs acceleration as suggested by Williams is consistent with the average acceleration for the long backing scenario and peak acceleration for short backers.

IMPLICATIONS RELATIVE TO COLLISION AVOIDANCE

With the equations, the system may compare the time to reach the object based upon the manner in which the drivers back, rather than based upon constant speed or acceleration. Most backing maneuvers are shorter, so the system should start with an assumption that the driver is backing a short distance. On the basis of the results in Figure 5, if the system detects a vehicle speed of greater than 2 mph and a positive acceleration rate greater than 0.06 Gs (during the previous 0.2 second), the system should assume a long backing acceleration and peak speed near 6.2 mph.

The present system detected movement and objects behind the vehicle to an extent of approximately 2 meters (6.5 ft). Glazduri (14) found the maximum detection distances from the rear of the bumper ranged from 1.05 m to 2.25 m (3.4 to 7.4 ft) for six other sensor systems. If we look at the avoidance opportunities mathematically, the results look bleak. If the warning system detected hazards up to 2 m (6.5 ft) behind the vehicle when traveling only 4 feet per second (2.7 mph) the total stopping distance (TBD) is over 12 feet ($4*3.05 + 4^2 / (2*32.2*0.5)$), suggesting that very few crashes could be avoided.

A collision warning system could be improved in ways that allow drivers' better understanding, attention to, and trust of a warning. Only then should a collision warning system be based upon an optimal response time (a brake activation system may work differently). Until then, this research shows that response times will be over 2 seconds when responding to a backup warning. While there may be greater contextual cues surrounding a real life warning (as an example, children playing in the area, a wall behind the vehicle and view of an object in the rearview video), the average response time of the short and long backers of near 2.5 seconds as a brake reaction time is a reasonable basis to work from to determine the range that a collision avoidance (warning) system must monitor. We should also keep in mind the system latency of no better than 0.1 second, but near 0.2 seconds (13, 14) and that braking latency will take near 0.25 seconds to reach 0.4 Gs deceleration and based upon this research, over 1.15 second to reach full pedal displacement.

The current research showed that drivers reached an average peak backing speed of 4.6 mph (2.1 m/s) for both short and long backing scenarios (2.68 mph for short backing and 6.17 for long backing). Logically, more backing scenarios will be shorter distances, rather than long backing scenarios. The available information suggests a detection area of 6 m (20 ft) may offer the best opportunity for drivers. This distance is based upon the stopping distance of drivers who respond as would the average driver in this research and also accounts for the area of obscured visibility in high profile vehicles as noted earlier. The model proposed here is somewhat corroborated the findings by Llaneras et al (8) who showed that drivers who were given a 2.14 second time to contact warning in a long backing situation (longer warning distance) responded more efficiently and reported the warning as being more timely.

If more backing maneuvers involve shorter distances, sensing ranges larger than the length of a parking space will likely lead to a greater percent of nuisance alarms. Interestingly enough, the typical parking space in the US is 5 to 6 m (16 to 20 ft) deep. This suggests a warning system that accounts for the backing distance required for a typical parking space should be sufficient to allow most drivers to avoid a crash. Since most drivers cannot see the area up to 6 m (20 ft) to the rear of their vehicle, it would be logical to have a detection system monitor that area.

The warning system should constantly monitor the vehicle speed acceleration during the previous 0.1 second (with the warning being relayed within 0.2 second). Different calculations will be performed based upon the speed and acceleration information. If the vehicle is slowing, drivers would have to be closer to the obstacle before receiving a warning than if accelerating when backing. If the system detects the vehicle is accelerating while backing and the acceleration rate is greater than 0.06 or the speed is greater than 2.68 mph, the system will assume the vehicle will increase backing speed up to 9 feet per second (6.17 mph). (See Figure 6).

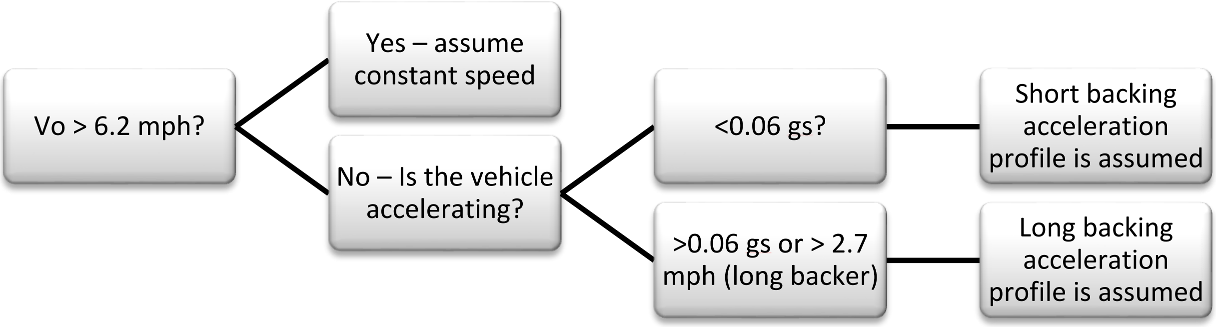

Figure 6 Flow chart showing the decisions leading up to a warning.

The sensor system in the vehicle tested offered an audible warning when within 2 m. We must agree with Mazzae and Garrott (28, 29 abstract) who concluded “Based on calculations of the distance required to stop from a particular vehicle speed, detection ranges exhibited by these systems were not sufficient to prevent many collisions with pedestrians or other objects.” However, we would add that some drivers were able to avoid hitting the surrogate pedestrian with the aid of the backing camera system and warning. It is clear that the combination of the two will likely reduce a small percent of crashes, but with system modifications has the potential to save several lives. Given the current short sensing range, automatic braking may also be an option, particularly since there is no significant fear of a different collision. Several manufacturers have a system that stops vehicles during low speed following, such as Volvo’s City Safety system (30). Such a system if applied to rear backing would circumvent a poor response by a driver, and may allow for shorter sensing ranges and assumptions of shorter response times in the stopping threshold. Our research addressed a warning distance, but our results corroborate the findings of Lerner, Kotwal, Lyons, and Gardner-Bonneau, (31) who recommended that a back-up warning device should include both a cautionary and a danger warning signal based on time to collision, if the danger warning also involves a braking assist of some type. At the very least, the backing speeds noted in this research and others suggest the current sensing range is too short even if response times were shorter.

A method has been proposed based upon total stopping distance and blind spot measurements as a warning. Clearly more research is necessary. Future research should examine the influence of a better warning sound, warning direction, self braking systems and determining the optimal total stopping distances that would account for the most drivers yet keep nuisance warning as a minimum.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the commitment and financial support of the National Science Foundation Center for Child Injury Prevention Studies (CChIPS) at The Children's Hospital of Philadelphia and its Industrial Advisory Board (IAB) for support of the original study on which these analyses were based and for technical guidance. The results presented in this report were the interpretation solely of the author(s) and were not necessarily the views of CChIPS or its IAB.

REFERENCES

1. Fenton, S, Scaife, E., Meyers, R., Hansen, K., Firth, S. (2005). The prevalence of driveway back-over injuries in the era of sports utility vehicles, Journal of Pediatric Surgery, 40, 1964-1968.
2. Olson, L. M., Sklar, D. P., Cobb, L., Sapien, R., Zumwalt. R. (1993) Analysis of childhood pedestrian deaths in New Mexico 1986 -1990. Annals of Emergency Medicine, 22: 512 - 6.
3. Centers for Disease Control and Prevention (CDC), (February 2005), Nonfatal motor-vehicle-related backover injuries among children--United States, 2001-2003, MMWR Morbidity Mortality Weekly Report, 54(6), 144-6.
4. Patrick, D. A., Bensard, D. D., Moore, E. E., Partington, M. D., Karrer, F. M. (1998). Driveway crush injuries in young children: a highly lethal, devastating, and potentially preventable event, Journal of Pediatric Surgery, 33, 1712-1715.
5. Murphy, F., White, S., Morreau, P. (2002). Journal of the New Zealand Medical Association, 115, 1 – 8.

6. Agran, P. F., Winn, D. G., and Anderson, C. L. (1994). Differences in Child Pedestrian Injury Events by Location, Pediatrics, 93, 284-288.
7. Brison R. J., Wicklund, K., Mueller B. A. (1988). Fatal pedestrian injuries to young children: a different pattern of injury, American Journal of Public Health, 78, 793-5.
8. Llaneras, R. E., Green, C. A., Kiefer, R. J., Chundrlik, W. J., Altan, O. D., Singer, J. P. (2005). Design and Evaluatio of a Prototype Rear Obstacle Detection and Driver Warning System, Human Factors, 47, 199–215.
9. Akcelik, R., & Besley, M. (2001). Acceleration and Deceleration Models. 23rd Conference of Australian Institutes of Transport Research (CAITR 2001). Melbourne.
10. Warner, C. Y., Smith, G. C., James, M. B., and Germane, G. J. (1983). Friction Applications in Accident Reconstruction, Technical paper No. 830612), Warrendale, PA: Society of Automotive Engineers.
11. Paine M. P., & Henderson, J. M., (2001). Devices to Reduce the Risk to Young Pedestrians from Reversing Motor Vehicles. New South Wales; Motor Accidents Authority of NSW. http://www.maa.nsw.gov.au/getfile.aspx?Type=document&ID=11514&ObjectType=3&ObjectID=1342
12. Consumer Reports, (October 2005). http://www.consumerreports.org/cro/cars/car-safety/car-safety-reviews/mind-that-blind-spot-1005/overview/index.htm downloaded 12, July, 2009.
13. Eberhard C., Moffa P., Young S and Allen R. (1995) Development of Performance Specifications for Collision Avoidance Systems for Lane Change, Merging and Backing. Development of Preliminary Performance Spec., National Highway Traffic Safety Administration, DOT HS 808, 430, September 1995.
14. Glazduri, V. (2005). An investigation of potential safety benefits of vehicle backup proximity sensors. Ottawa, Ontario: Transport Canada. Technical paper No. 05-0408.
15. Scott, P.A., Candler, P.D., and Li, J.e. (1996). Stature and seat position as factors affecting fractionated response times in motor vehicle drivers, Appl. Ergonomics, 27, 411-416.
16. Koppa, R.J., Fambro, D.B., and Zimmer, R.A. (I996). Immediate and long-term effects of glare from following vehicles on target detection in driving simulator, human performance, driving simulation, information systems, and older drivers. (Transportation Research Record 1550). Washington, D.C.: National Academy Press
17. Parkes, A. and Hooijmeijer, V. (2000). The influence of the use of mobile phones on driver situation awareness, Cawthorne, England: Transport Research Laboratory.
18. Barrett, G., Kobayashi, M., and Fox, B.H. (1968). Feasibility of studying driver reaction to sudden pedestrian emergencies in an automobile simulator, Hum. Factors, 10, 19-26.
19. Otto, W.M., Otto, C.L., and Overton, R.K. (1980). Response characteristics of motorcycle riders to a complex emergency situation, Washington, D.C.: Int. Motorcycle Safety Conf Proc., IV, 1489-1503.
20. Broen, N.L. and Chiang, D.P. (1996). Braking response times for 100 drivers in the avoidance of an unexpected obstacle as measured in a driving simulator, Proceedings Human Factors Ergonomics Society 40th Annual Meeting, 900.
21. van Winsum, W. (1998). Preferred time headway in car-following and individual differences in perceptual motor skills, Perceptual Motor Skills, 87, 863-873.
22. McGehee, D.V., Mazzae, E.N., and Baldwin, G.H.S. (2000). Driver reaction time in crash avoidance research: validation of a driving simulator study on a test track, Proc. Int. Ergonomics Assoc. 2000 Conf, 3, 320-323.
23. Muttart, J. W., Fisher, D. L., Pollatsek, A., & Knodler, M. (2007). Driving Without a Clue: Evaluation of Driver Simulator Performance During Hands-Free Cell Phone Operation in a Work Zone, Transportation Research Board of the National Academies, Volume 2018. Safety and Human Performance, pp. 9-14.
24. Hurwitz, D. S., Pradhan, A. K., Fisher, D. L., Knodler, M. A., Menon, R., Meissner, U. (2009). Backing collisions: A study of driver's eye and backing behavior using combined rear view camera and sensor systems (in press).
25. Harpster, J., Huey, R., and Lerner, N. (1996). Field measurements of naturalistic backing behavior, Proceedings of the Human factors and Ergonomic Society 40th Annual Meeting.
26. Williams, H. S. (1999). Microwave Motion Sensors for Off-Road Vehicle Velocity Data and Collision Avoidance, Sensors Magazine.

27. Yerkes, R. M., & Dodson, J. D. (1908) The relation of strength of stimulus to rapidity of habit-formation. Journal of Comparative Neurology and Psychology, 18, 459-482.
28. Mazzae, E. N., Garrott, W. R. (2008). Light vehicle rear visibility assessment. DOT HS 810 909; NHTSA/NVS-312, Washington, DC: National Highway Traffic Safety Administration.
29. Mazzae, E. N., Garrott, W. R. (2006). Light vehicle rear visibility assessment. DOT HS 810 634; NHTSA/NVS-312, Washington, DC: National Highway Traffic Safety Administration.
30. Volvo New & Events, accessed November, 12, 2009. http://www.volvocars.com/intl/top/about/news-events/pages/default.aspx?itemid=21
31. Lerner, N. D., Kotwal, B. M., Lyons, R. D., and Gardner-Bonneau, D. J. (1996). Preliminar yhuman factors guidelines for crash avoidance warning devices (Report No. DOT HS 808 342). Washington, DC: U.S. Department of Transportation.