Operation ALIVE (Automobile submersion: Lessons In Vehicle Escape)

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Abstract

Vehicle submersion carries one of the highest mortality rates of any type of single-vehicle accident. In North America ~400 individuals/yr die in submersed vehicles; in Canada 7% of all drownings occur in vehicles. A search of research, educational and public service information, plus a public survey identified the following probable significant contributors to this high fatality rate: 'authorities' provide contradictory advice and inadequate description of vehicle sinking characteristics; and poor public perception of how to escape; approximately half feel that they should stay in the vehicle while it fills with water or even until it sinks to the bottom.

Generally, vehicle characteristics in water are described with one variable; the amount of time until the vehicle is completely submerged. In *Operation Alive* (Automobile submersion: Lessons In Vehicle Escape) we used a crane to conduct repeated vehicle submersions with trained volunteers attempting various exiting strategies throughout the submersion process. Based on our trials, we conclude that vehicles pass through three distinct phases after landing in water, and that public awareness of these phases would help increase understanding of proper exit strategies.

Therefore we propose adoption of the following description for the three phases of vehicle behavior in water: 1) Floating. Initially a vehicle floats for 30 seconds to 2 minutes before the water reaches the bottom of the side windows, which provides ample time to exit the vehicle. During this phase windows can be easily opened and used for exit. The doors should never be opened because this allows rapid influx of water and could cause the vehicle to submerge very quickly—within seconds. Normally there is adequate time to escape during this phase. In one trial, three adults were able to exit a single window (driver's side), including the release of a child manikin from a rear child seat, within 51 seconds. 2) Sinking. The sinking phase extends from the time when the water rises above the bottom of the side windows to when the vehicle is completely under water, but before the inside fills completely with water. During this period occupants can breath as water is rising inside the vehicle. However, the water level is higher outside, which exerts pressure against the doors and windows and makes them very difficult or impossible to open. As the vehicle fills with water, it tilts engine-end down into an almost vertical position. The chances for escape and survival decrease considerably during this phase; and 3) Submerged**.** The vehicle is full of water and no air pockets exist, this can occur either before or after the vehicle lands on the bottom, depending on the water depth. If the vehicle is full of water and on the bottom, the chance of survival is negligible.

Clearly the best time to escape from a vehicle is immediately during the initial floating phase. The following escape procedure should be followed: Seatbelt(s) unfastened; Children released from restraints and brought close to an adult who can assist in their escape; Windows open; and Out, children should be pushed out of the window first, and followed immediately.

Résumé

Lorsqu'on parle des accidents d'automobiles, saviez-vous que l'accident qui a le plus haut taux de mortalité et l'accident qui a le plus haut classement d'accident sont les accidents où les automobiles sont immergées dans l'eau. Dans l'Amérique du Nord environ 400 gens par année meurent lorsque les automobiles sont immergées; au Canada 7% de toute noyade arrive à cause des automobiles. Une recherche absolue de toute l'information, éducative

et publique, a trouvé qu'il y a qeulque causes de ce taux haut de mortalité: Les avis disséminent par les autorités sont inappropriés en ce qui concerne les accidents d'automobile dans l'ea. Et le point de vue du publique de comment évacuer est insuffisant; 50% pense que tu dois rester dans l'automobile pendant que l'eau entre dans la véhicule, ou jusqu'au point que l'automobile arrive au font.

En général, les caractéristiques d'automobiles dans l'eau sont expliquées avec un seul variable; le montant de temps qu'il prenne avant que l'automobile est complètement dessous la face d'eau. En *Operation Alive* (Automobile submersion: Lessons In Vehicle Escape) une grue était habituée pour répéter les immersions d'automobiles. Les personnes qui étaient bien entraînées essayent de différentes façons de sortir pendant l'immersion. Fondé sur nous déboires, nous avons établi trois périodes de temps après d'être immerger dans l'eau. Il faut éduquer la publique à sujet de ces trois périodes de temps pour que les personnes dans une telle situation peuvent sortir en sécurité.

Donc, nous proposons que les descriptions suivantes soient adopter pour les trois périodes de temps quand une automobile est immergée dans l'eau. 1) Flottaison. Une automobile reste dans cette position pour 30 secondes à 2 minutes avant que l'eau atteint la hauteur des fenêtres. Il y a encore du temps pour sortir par la fenêtre pendant ce temps. Les fenêtres peuvent être ouvertes facilement, mais les portes ne doivent pas être ouvertes parce que l'eau peut entrer très vite. Habituellement, il y a suffisamment du temps pour sortir de l'automobile dans cette période de temps. Dans un essai trois adultes sont sortis de l'automobile par la fenêtre sur la côté du chauffeur en 51 seconds avec un mannequin d'enfant; et 2) Engloutissement. La période de temps pour l'engloutissement et après que l'eau atteint la hauteur des fenêtres à côté au point que l'auto est complètement dessous la face d'eau, mais que l'intérieur de l'automobile n'est pas encore pleine d'eau. Dans ce temps les passagers peuvent respirer l'air piège dans l'auto, pendant que l'eau entre. Cependant, l'eau qui se retrouve à l'extérieur de l'auto atteint une échelle de plus que l'eau à l'intérieur de l'auto, avec cette pression les portes et fenêtres sont difficiles à ouvrir. Au moment où l'auto remplit avec l'eau, elle commence a plongée et elle est inclinée, le bout de l'auto où se trouve la moteur plonge en premier lieu. Les chances de sortir en sécurité descend pendant cette période de temps; et 3) Submerger. L'auto est complètement dessous la face d'eau, et l'intérieur de l'automobile est aussi pleine d'eau. Il n'y a pas d'air piège dans l'auto pour respirer, ceci peut arriver avant ou après que l'auto atteint le font. Si l'auto est au font, est il n'y a pas d'air piège et les chances de survivre sont minimes.

La meilleure possibilité de sortir d'une automobile qui est submergée dans l'eau est pendant la période de temps où l'auto flotte. La prochaine procédure devrait être talonne: Ceinture de sécurité(s) détacher; Enfants détacher les ceintures de sécurités, c'est la responsabilité de l'adulte pour les aider à évacuer ; Fenêtres ouvertes; et Sortir, il faut assister aux enfants premièrement.

Introduction

Vehicle submersion has one of the highest mortality rates of any type of single-vehicle accident.

Country (Year(s))	Drownings in Vehicles	% of all Accidental Drownings	% of all Vehicle Fatalities
Canada (1997)	56	10.0	2.2
New Zealand (1977-93)	18	11.4	4.7
Norway (1999)	78	11.0	2.3
Finland (1997)	17	5.6	3.9
USA (1999)	350	10.0	1.0
United Kingdom (2002)	20	4.7	0.6

Table 1.
Vehicle deaths in water reported as a percentage of all drowning deaths, and all vehicle deaths.

In North America ~400 individuals/yr die in submersed vehicles; in Canada between 7-10 % of all drownings occur in vehicles; similar ratios occur in other industrialized nations (Table 1) (1-7).

There are very few refereed research articles on the topic of vehicle submersion (5, 6, 8-10) and they are generally epidemiological in nature.

A review of educational and public service information, plus a public survey identified three probable significant contributors to this high fatality rate: 1) 'authorities' provide an inadequate description of vehicle sinking characteristics; 2) contradictory and incorrect advice is often provided; and 3) a poor public perception of how to escape.

First, authorities generally describe vehicle characteristics in water with one variable. "Flotation time" includes the entire period from when the vehicle lands in the water until it is completely submersed (11, 12). Unfortunately, preliminary trials indicate that conditions, and chance of survival, change considerably during this inclusive period and should be described more effectively to reflect these different phases.

Second, several sources advise the public to stay in the vehicle and take actions such as: holding on to the steering wheel; let the passenger compartment fill with water so that it will be easier to open the doors; wait until the vehicle hits the bottom in order to maintain orientation; rely on kicking out windshields; opening the door to exit; having tools for breaking the windows but placing them in the glove compartment or under the seats; and reliance on breathing trapped air in the passenger compartment (13-21).

Many of these questionable practices are reinforced in many popular media venues (16, 22-25).

Third, approximately half, or more, of the general public identify with some option that involves staying in the vehicle while it fills with water or even until it sinks to the bottom (Figure 1). These strategies would seem to decrease the chance of survival.

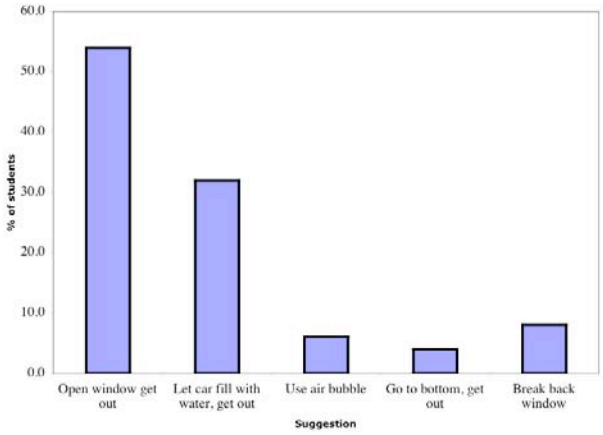

Figure 1.
Responses from 50 university students asked what they would do if their vehicle is in the water.

Operation ALIVE (Automobile submersion: Lessons In Vehicle Escape) is an ongoing investigation aimed at providing information on how people can deal with different exit challenges that occur with different types of vehicles (i.e., cars, vans, trucks, heavy equipment etc.) in summer and winter conditions.

This paper reports on data and experiences derived from 35 vehicle submersions conduced in two locations in summer (open water) and winter (ice breakthrough). There were several goals including: to confirm passenger car sinking characteristics and factors that might affect these characteristics; determine ease or difficulty of vehicle egress under different conditions; determine how quickly various subject groups can exit a vehicle before it sinks; and to propose an educational approach to decrease the death rate of these accidents.

Methods

In *Operation Alive* a crane was used to conduct repeated vehicle submersions with the vehicle either

empty or with trained volunteers attempting various exiting strategies throughout the submersion process. All submersions were video taped for later analyses.

Testing was conducted once in the ocean at Homer, Alaska in August, 2005, and twice in a quarry near Winnipeg in October and December, 2005. A total of 35 vehicle submersions were conducted with two 1992 Ford Tempos.

The passenger compartment was completely intact in the vehicle used in the first trials (Vehicle #1). The vehicle used for the later two trials (Vehicle #2) had holes in the floor boards with a total area of ~2200 cm^2 (350 in^2). After the first immersion with Vehicle #2, the holes were closed to create as intact a passenger compartment as possible.

Vehicles were rigged in such as way that they could either sink completely free of the crane restraints, or under control of the crane.

In trials involving human subjects. The vehicles were equipped with SCUBA tanks attached to the front and rear of the passenger compartment. Regulators were attached at known locations in the front and back. Two trained backup/rescue SCUBA divers were positioned just outside and/or inside the vehicles to provide assistance if required.

Subjects were trained SCUBA divers who practiced, and were prepared for, breathing from the emergency air sources within the car if they could not exit the vehicle as planned for the trial. The vehicle was never completely disconnected from the crane so the vehicle could be raised from the water in all situations. In the case of a crane failure, rescue divers were ready to either open the door or break the windows in order to assist the subject from exiting the vehicle.

Results

Car sinking characteristics. At the beginning of each set of trials, each vehicle was allowed to freely sink while its attitude and sink rate were determined. Both vehicles were the same model and year (Ford Tempo, 1992). The second vehicle sunk much quicker than the first. After it was determined that the floor had large holes in it, the holes were repaired and the submersion trial was repeated.

In the first set of trials, the subject opened the door soon after the vehicle contacted the water in order to compare the sink rates with the door closed and opened.

Results for several sink rate trials are presented below in Table 2. "Floating time" refers to how long it took the water to reach the bottom of the side windows, and "sinking time" refers to the remaining time until the car was completely submersed.

Submersion Trial	Floating Time (sec)	Sinking Time (sec)	Total Time to Submersion (sec)
Vehicle #1 Passenger Compartment Intact (Doors and windows closed)	63	87	150
Vehicle #1 Driver Door Forced Open	9	21	30
Vehicle #2 Passenger Compartment Compromised (Doors and windows closed)	15	22	37
Vehicle #2 Passenger Compartment Repaired (Doors and windows closed)	26	45	71

Table 2.
Vehicle sinking characteristics.

Opening the vehicle door greatly decreased the time that the vehicle remained afloat. As well, the door slammed shut forcefully due to a rapid pressure buildup as the vehicle submerged quickly.

The integrity of the passenger compartment has a large effect on sink rate. Vehicle #2, with the holes in the floor, sunk much faster than its counterpart; this effect was mitigated by repairing the holes.

Ease of vehicle egress. If exit was attempted before the water rose above the bottom of the side windows, the manual windows were easily opened and egress through the windows was easily achieved by all subjects.

Once the water level rose above the side windows, the water level was lower inside the vehicle. The positive pressure gradient from outside to inside the vehicle made it virtually impossible to open the doors and very difficult to open the window because it was being pushed against the window frame. In these trials, subjects had to wait until the passenger compartment was almost completely full of water before the windows or doors could be opened.

Based on these trials, we conclude that vehicles pass through three distinct phases after contacting the water: floating, until the water reaches the bottom of the side windows; sinking, when water rises above the bottom of the side windows and the outside water level is higher that the level within the passenger compartment; and submerged, when the vehicle is almost, or completely, filled with water (see Discussion).

Speed of egress. These trials were conducted during the floating phase in which the water was not yet above the bottom of the side windows; if required the crane kept the vehicle from sinking further. Each scenario was timed. Several trials included one or more subjects exiting through one or more windows. Escape times are presented in Table 3.

Subject(s)	Exit Route(s)	Total Exit Time (sec)
Driver	Driver side front window	10
Driver, Front Passenger	Driver side front window	22
Driver, Front Passenger, Rear passenger	Driver/Passenger front windows	12
Driver, Front Passenger, 2 Rear Passengers	Driver/Passenger front windows	29
Driver, Child in rear car seat	Driver side front window	18
Driver, Front Passenger, Child in rear car seat, Child rear passenger	Driver/Passenger front windows	26
Driver, Front Passenger, Rear Passenger, Child in rear car seat	Driver side front window	51

Table 3.
Vehicle exit times
for various subject/route combinations.

Figure 2 illustrates one trial in which three passengers and a child manikin were removed from the vehicle within 51 seconds.

Figure 2.
Escape exercises.

Discussion

To our knowledge, this series of studies is the first large scale vehicle submersion study using human subjects participating in different exit strategies.

These trials showed that opening a vehicle door once the vehicle is in the water, greatly increases the sinking rate, and results in the door being forcefully shut, potentially endangering the passenger him/herself, or trapping others inside the vehicle is it is rapidly submersed.

These trials also demonstrated that a vehicle passes through three phases during submersion that each relate differently to exit strategies and potential for survival. We propose that vehicle sinking be described as follows:

1) Floating. Initially a vehicle floats for 30 seconds to 2 minutes before the water reaches the bottom of the side windows, which provides ample time to exit the vehicle. During this phase windows can be easily opened and used for exit. The doors should never be opened because this allows rapid influx of water and could cause the vehicle to submerge very quickly—within seconds. Normally there is adequate time to escape during this phase. In one trial, three adults were able to exit a single window (driver's side), including the release of a child manikin from a rear child seat, within 51 seconds.

Figure 3.
Floating Phase

2) Sinking. The sinking phase extends from the time when the water rises above the bottom of the side windows to when the vehicle is completely under water, but before the inside fills completely with water. During this period occupants can breath as water is rising inside the vehicle.

However, the water level is higher outside, which exerts pressure against the doors and windows and makes them very difficult or impossible to open. As the vehicle fills with water, it tilts engine-end down into an almost vertical position. The chances for escape and survival decrease considerably during this phase.

Figure 4.
Sinking Phase

3) Submerged**.** The vehicle is full of water and no air pockets exist, this can occur either before or after the vehicle lands on the bottom, depending on the water depth. If the vehicle is full of water and on the bottom, the chance of survival is negligible.

A vehicle normally will be floating for 30 to 120 seconds before water reaches the bottom of the side window. We demonstrated that this is enough time for fairly complicated escape strategies to be employed as long as subjects were prepared for what to do. Alternatively, it is difficult or impossible to exit a vehicle once it has reached the sinking phase due to the greater pressure on the outside of the vehicle.

Figure 5.
Submersion Phase in a vehicle which has broken through the ice.

It is important to inform and train the public of these factors so that they become second nature. This will greatly increase the probability of persons initiating the proper exit strategies when faced with an emergency situation with little time to rationally think of a course of action.

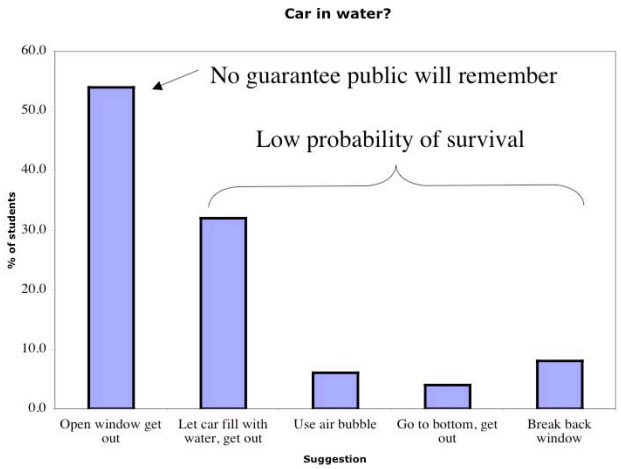

Figure 6. Prolems with various escape strageties.

Clearly the best time to escape from a vehicle is immediately during the initial floating phase. The following escape procedure should be followed:

- Seatbelts
- Children
- Windows
- Out

This means: Seatbelt(s) unfastened; Children (if present) released from restraints and brought close to an adult who can assist in their escape; Windows open; and Out, children should be pushed out of the window first, and followed immediately.

Vehicle manufacturers now construct vehicles in which the electronics should work for up to 3 minutes once submerged. If a vehicle has electronic windows which work adequately, they should work especially during the important floating phase. One added safety consideration would be to have a centre punch mounted in an obvious place, which could be used to break the window if it does not open.

Finally, a growing trend in our society is the tendency to call 911 during an emergency, with this process being easier with increased popularity of the cell phone. The standard 911 operator response to an emergency call is to gather information about the situation including location of the accident so help can be dispatched (26). In the case of submersed vehicles, valuable time is wasted as it takes 30 to 90 seconds to make a cell phone call; a period that precludes the victim from escaping during the simpler and safer floating phase. As well, there is no rescue system that guarantees arrival on site within 2 minutes; which would be required to achieve successful rescue.

We suggest that public education focus on immediate self rescue through exit during the floating phase. Also, 911 response protocols should be developed specifically for vehicle submersion cases, in which the operator should focus attention on instructing the victim that they must exit the vehicle through the windows as quickly as possible.

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