Using Driving Simulators to Expand Moose Perception Data: Some results and validity issues.

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ABSTRACT
Moose collisions injure and kill a multitude of animals and humans each year. While in-vehicle warning systems are under development, the evaluation of these systems is a challenging process. In comparison with traditional on-road instrumented vehicles, driving simulators offer safer testing environments, but pose validity concerns. To understand the validity issues, this study replicates and expands upon Robins's [1] on-road findings in “Moose Visibility Distance in Nighttime Highway Driving Conditions: A Preliminary Investigation”. The significant effect of moose location on perception time is supported while our data suggests that typical speed limits are even more problematic than Robins demonstrated. The results are discussed with a focus on understanding the validity of simulated driving and establishing future validation research directions.

INTRODUCTION
Moose collisions are a major roadway safety concern and a detriment to the fragile environmental equilibrium. They also cause substantial vehicle damage, costly rehabilitation of injured drivers, and in some cases moose collisions can be fatal.

In the hopes of helping drivers avoid such collisions, a number of early warning systems are in development and/or deployed for various obstacles including large animals [2-4]. In determining the effectiveness of any warning system, a baseline condition must be established to understand how well people perceive and react to an object without the aid of a warning system. This paper focuses on establishing a baseline using a driving simulator in which the simulated scenario is based on a previous on-road study [1]. This provides a means to compare simulated and on-road behaviours and in turn acts as a tool for understanding the validity of using a simulator under these conditions.

In addition, moose visibility studies can be used to determine the speed to which drivers should limit themselves in order to safely travel in areas populated with moose.

INSTRUMENTED VEHICLE STUDIES
Prior to the 1980s, driving research was limited to instrumented cars on roadways or on closed circuit tracks. On-road research provides perfect driver-environment contiguity and realism, but, has many disadvantages. For example, some experimental manipulations are unethical and dangerous. In the case of moose avoidance studies, pushing a moose decoy into the path of an oncoming driver could lead to an unintended accident. This type of danger further restricts experimentation with clinical participants, as they pose additional safety risks to both themselves and to the experimenters [5].

In addition, on-road studies cannot offer the situational control nor the near perfect test consistency that driving simulator studies take for granted. Furthermore, the treatments possible in on-road studies (such as a moose decoy) are often so artificial that behavioral validity becomes a serious concern [6].

DRIVING SIMULATOR STUDIES
Simulated environments are safe environments for evaluating driver reactions to on-road obstacles. However, simulators have numerous negative qualities. Ironically, one of those is related to the inherent safety of the simulator; the lack of danger in driving simulators may impact how drivers react to simulated dangerous events, such as moose encounters, i.e., they may not take the challenge of safe driving seriously while in the simulator.

The quality of the driver’s experience within the simulated environment is also a concern for experimenters. Simulator fidelity is particularly important in driver behaviour studies of road characteristics and visibility conditions [7]. Many environmental on-road cues are either approximated or absent in the simulator.
While some cues can be implemented in driving simulators to improve the participant's experience, such as providing a wide field of view to allow for better speed perception [8], others simply defy current technological possibilities. For example, low resolution textures, limited by current graphical processing units, can impede the perception of distance [9]. Also, the lack of physical feedback can severely alter a driver's reactions, e.g., when simulated gusts of wind provoke steering compensations [10]. Even technologically advanced simulators with outstanding visuals and both planar and tilting motion capabilities fall short of attaining the ideal fidelity. The resulting disparity between visual and kinetic feedback often leads to participants experiencing simulator sickness [11]. In summary, driving simulators provide ideal experimental control and precision, but in an approximated environment.

CHOOSING THE VALID APPROACH

Since neither on-road nor simulator approaches are ideal, understanding their limitations and costs is an important consideration. In general, using both approaches can become extremely knowledge and resource intensive, and as a result, researchers usually resort to only one approach. The ideal approach is the one that provides the greatest validity while still answering important research questions. In some cases deciding how to perform the research can be very difficult, while in other cases, it may be very straightforward, e.g., when a simulator is unavailable.

Since the concern of moose avoidance research is to study the driver's perception and reaction, both approaches offer advantages and disadvantages. For example, on-road studies could use of extremely realistic moose decoys, but for reasons of safety would not permit drivers to cruise towards them at typical roadway speeds. On the other hand, driving simulators allow the safe study of high-speed moose encounters, but provide reduced sensory realism. Neither approach is comprehensive, and both raise concerns over the validity of the results. More specifically, there may be compromises to the internal validity, the extent to which the measurement truly yields a good impression and understanding of the construct of interest. As well, this may hold true for external validity, i.e., whether the observed treatment effects are predictive of events and behaviour outside the experimental setting. As a result, this may limit the conclusions that can be drawn.

In some cases, resorting to the exploitation of both approaches may be the only option. Should the results from both types of experimentation yield similar findings, then, in principle, inferences drawn from the data are considerably more likely to be correct. Rather than performing both an on-road and simulator experiment, our study attempts to balance the results of a previous on-road study by replicating the experiment in a driving simulator. Validity issues will be dealt with by comparing the results from both studies.

ON-ROAD FINDINGS

Robins [1] found that moose position had an effect on when it was first observed. Specifically, a moose decoy could be seen furthest away if it was placed in the center of the driving lane; from not quite as far if it was placed on the right shoulder of the road; and from even less far if it was placed on the left shoulder of the road. In addition, a headlamp manipulation (low beam vs. high beam setting) yielded another significant effect on moose perception distance; moose can be detected from further away when the driver makes use of the vehicle's high beams. These perception distances were then used by Robins to calculate the maximum cruising speed that would allow a vehicle to be safely stopped, given moose perception distance, literature proposed perception and reaction times, as well as braking time requirements. In conclusion, to allow enough time for detecting, reacting and stopping to avoid hitting a moose, Robins suggested that while using low beam headlamps, drivers should not drive faster than 60km/h whereas with a high beam setting, drivers should not drive at speeds greater than 80-90km/h [1].

It is difficult to simulate a moose decoy that could be used to determine an absolute detection distance. However, the simulator could be used to determine the relative driver perception times at typical rural two-lane highway speeds (90km/hr) to the three moose positions used by Robins [1]. To this end, a study was performed in the DRIVE Lab simulator at a crawling speed of 15km/h, to replicate Robins [1] on-road research, and also while drivers cruised at speeds around 90km/h.

METHOD

The experimental setup consisted of a fixed-based instrumented class D cab (constructed by Global Sim) with 5 forward projection screens, covering a total of 250 degrees of forward view and single 50 degree projection to the rear. The remaining 60 degrees is split between the two rearward blind spots. Each projection screen displays a 1024x768 pixel image on a 7-foot (measured diagonally) screen. The simulator ran DriveSafety's Vection simulation software, with scenarios designed using Hyperdrive. Data, collected at a rate of 60 Hz, captured pedal pressure, virtual position of the vehicle and its velocity.

MOOSE STIMULUS

A three dimensional moose decoy was designed with a dark brown color. The moose was proportioned to mimic a mature adult moose. Limited by the resolution of the projection screens, the first pixel to change as a result of the moose appearing in the display occurs at a distance of 78.5 meters. A panel of human judges determined that the moose was fully recognizable at a distance of 75 meters. An example of the decoy can be seen in Figure 1.
Students from the University of Guelph were invited to participate in our study. All participants needed to have had at least five years of driving experience, a graduated license allowing them to drive without supervision, and pass a screening test designed to predict their likelihood of experiencing simulator adaptation syndrome. This screening questionnaire also had the potential to uncover individuals with a propensity to motion sickness, balance problems, claustrophobia or migraines. Individuals who were determined to be at a high risk of experiencing discomforts were not invited to proceed further with the experimentation.

Eight participants (6 men, 2 women, average age = 24 years, SD = 5 years) each completed the study. All drivers were familiar with moose, although only five of them had encountered moose or deer as part of their driving experience. As remuneration for their participation, they were offered a t-shirt.

PROCEDURES

After arriving at the laboratory, participants were briefed on how to operate the simulator, and told they should drive the simulator as they would a real car. They were then informed they would drive through three scenarios.

The first scenario was for practice and gave them a feel for the car and get used to stopping for the occasional moose. The goal was to give participants a good understanding of their task along with a chance to ask questions. On completing the practice scenario, they were told they were to drive in a normal manner and that their driving behaviour would be recorded.

The scenarios simulated a night-time driving conditions on a 2-lane rural highway bordered by lines of tree (as in Robins’s original study [1]). Although participants were allowed to explore the vehicle’s
dynamic properties for the experimental condition, they were specifically instructed to follow a 15km/h speed limit (condition 1) and a 90km/h speed limit (condition 2) for the experimental scenarios. Since any effect observed due to the use of different headlamp settings might have merely reflected the simulator’s configuration, high beams were used throughout the three scenarios.

Participants were asked to bring the vehicle to a complete stop on sighting a moose. These occurred approximately every 1400-1800 meters in the 90km/h scenario and approximately every 200-500 meters in the 15km/h scenario. A total of 12 moose per encounters were interspersed in an unpredictable fashion. Four were placed on the left shoulder of the road, four were placed in the center of the driver’s lane and four were placed on the right shoulder of the road. In each case, the moose was positioned looking towards the driver’s left side (see Figure 1).

Following the practice scenario, four participants proceeded with condition 1, whereas the four other participants proceeded with condition 2, so as to minimize any resulting practice effects. The practice scenario took approximately five minutes to drive through whereas the experimental scenarios took approximately 15 minutes to complete. A five minute break was taken between each of the three scenarios.

MEASURES AND THEIR DERIVATIVES

At a distance of 75m from each moose (where a driver is capable of recognizing the moose for the first time), measurement collection began. Measurements included a timestamp, the vehicle’s velocity and the pressure on the accelerator pedal.

A second set of measurements was taken once the participant had released the accelerator pedal, i.e., at the first observable sign the participant may have perceived the moose. The difference in time between the two measurements indicates the perception time and the distance of the vehicle away from the moose at that point was defined as the perception distance.

A third set of measurements was taken once the participant began to apply pressure to the brake pedal. The difference in time between the second and third measurements was defined as the motor time (the time it takes to move one’s foot between the two pedals).

Finally, a fourth set of measurements was taken once the vehicle was brought to a halt. The velocity at the onset of braking (3rd measurement) divided by the time lapsed since the third measurement yielded the average braking deceleration. The distance from this point to the moose was defined as the distance when stopped, with negative values representing a stopped position beyond the position of the moose (implying a collision when the moose was positioned in the center of the driver’s lane).
RESULTS

Out of a total of 192 data points, 46 were excluded from the analysis for the following reasons: Four data points were taken while a participant drove using the low beams setting. For 11 other data points, participants already had their foot off the accelerator pedal at the 75m distance from the moose, where it is first visible, preventing the determination of the perception time. Finally, 31 data points were excluded because participants had never released their foot off the accelerator pedal prior to passing the moose. These instances, for the most part, likely represent misdetections, occurring because the driver was bored and distracted (not unlike real world driving). We suspect however, that a few of these data points may have been instances of ‘giving up’, where the participant realized that they took too long to perceive the moose and would not likely be able to stop on time. In such a case, they would have simply decided to keep moving along towards their next encounter, at which point they could try again. This type of reaction, reported once by a participant after driving through a specific encounter, is an indicator to the lack of criticality within driving simulators. Giving up on the road would have much more serious consequences. The remaining 76% of the data yielded the following results:

For the 15km/h condition, moose position had a significant effect on perception distance (ANOVA, F=5.855, p<.01), more specifically the left moose position requiring the driver to be significantly closer (mean=51.32m, SE=1.88m) for the perception of the moose than for the center lane (mean=56.13m, SE=1.43m) and right (mean=60.32m, SE=2.04m) moose positions. This effect is displayed in Figure 2. The perception distance for the center lane and right moose position did not significantly differ from each other (p>.05) and thus form a homogenous subgroup. Moose location did not significantly affect perception distance in the 90km/h condition (p>.05). With both conditions combined, moose position had a significant effect on perception time (ANOVA, F=6.39, p<.01) with the left shoulder position (mean=3.88s, SE=.429) taking significantly longer than the right shoulder position (mean=2.01s, SE=.281) with the lane center position (mean=2.96, SE=.340) not being significantly different from the other two (p>.05). This finding can be seen in Figure 3.

The cruising velocity (15km/h vs. 90km/h) had a significant effect on many variables, most notably perception time, motor time, braking deceleration and distance when stopped (ANOVA, F1=83.69, F2=21.51, F3=2413.56, F4=778.16, P1-4<.01). More specifically, when cruising at 90km/h, participants had shorter perception times, shorter motor times, greater average decelerations and had smaller distances when stopped. In other words, although they reacted faster and pressed harder on the brakes, they still ended up closer to the moose, with a spread implying many collisions.

DISCUSSION

Our data supports Robins’s [1] finding that moose position can influence the perception distance (also indirectly supported using a perception time measure) with the left shoulder position being the most difficult to perceive. It is possible that drivers develop a bias towards paying attention to right sided events due to practice with read roadway signage and being on guard for unexpected pedestrian and cyclists. Certainly,
the difference in distance between the driver and the left shoulder or right shoulder positioned moose is virtually negligible at the typical perception distance found. Regardless of its explanation, this replicated finding shows additional validity to the simulator approach.

When attempting to validate a method, it may be unnecessary to obtain precisely the same manipulation effect ratios between experimental designs, but the treatment effects should follow the same trend [6]. This is precisely the type of result this data yielded. The left shoulder moose position consistently required the participant to be closer for its perception. It is a bit unclear as to whether, with increased power, we would obtain consistently significant differences between the right shoulder and center lane positions. It may be worth reviewing the data obtained by Robins and running post hoc tests on his moose position data or to replicate the on-road study with an increased sample size. Either way, it appears as though using driving simulators for determining relative perception distances of various stimuli are not out of the question. The current limitation of not being able to reproduce the absolute perception distance to match on-road data may actually dissipate as projection screen resolution improves. In the mean time, simulators are proving to be very powerful tools, making possible research that would otherwise be too expensive or dangerous using the on-road approach [12].

Given the consistency in results for the effect of moose location on perception distance, it’s likely that the data for the 90km/h is reasonably trustworthy. One clear trend however, is that while crawling, participants take advantage of their low velocity and don’t take action as urgently. In the 90km/h cruising speed condition participants seem to have a really good understanding of how much harder it is to stop on time and behave as though they require less conviction prior to taking action. With a quicker perception time (likely because of a lower decision threshold), a shorter time and with immediate full pressure on the brakes, participants still don’t necessarily stop on time. However, even in the safe haven of the driving simulator, drivers do take more timely action in critical situations. The remaining validity question pertaining to this issue is whether or not participants would have even shorter perception times if they were tricked into thinking that a mistake could be lethal. The large number of trials (slightly more than 15%) where participants simply went through without slowing down might give some indication of this. We shouldn’t forget that either approach has one considerable issue that neither can truly address, which is that of expectancy.

Because both approaches are expensive and time consuming, within-participant experimental designs are generally used to increase statistical power and allow for conclusions to be reached with considerably less data. Unfortunately by having repeated measures participants become familiar with the moose decoy and knew to pay attention because it was only a matter of time before it would show up again. Being tested for the reaction to multiple moose encounters within an hour is very different from the real driving situation when one might encounter a moose at the lesser rate of less than once per season.

There was significant difference between the overall average perception times of participants, the result of a much greater between-participant than within-participant variance in perception times. This indicates that drivers are idiosyncratic and that any conclusions based on summarized data should be accompanied by confidence intervals or standard deviations. Also, this additional variance in perception time should encourage us to be conservative when stating conclusions regarding safe cruising velocities.

In our repeated measures 90km/h condition, the average perception time was 1.32 seconds (SD=.426s, 95% upper confidence boundary=1.42s) with an average motor time of 0.186 seconds (SD=.053s, 95% upper confidence boundary=.198s). Taken additively, this implies that from the onset of the moose first being visible, it took participants 1.61 seconds to react. This is considerably longer than the suggested 1.25 seconds by Robins, especially considering that the element of surprise was not factored in, i.e., on-road moose encounters would neither be practiced, nor expected. Since others have suggested adding at least an additional 200 milliseconds to the motor time of unexpected reactions times [13], the reaction time in a normal situation would be at least 1.81s. Furthermore, age and secondary tasks are other factors which tend to slow down reaction time [14].

Given as how our participants were young and not engaged in secondary tasks, the typical driver would need much longer than the 1.81s we found. It may be much more realistic to go with the 2.5s reaction time observed in a study evaluating the reaction time to unalerted light stimuli on a dark road [15] and recommended by AASHTO (American Association of State Highway and Transportation Officials) [1]. This would in turn imply that a maximum velocity, allowing one to stop on time to avoid colliding with a moose, of less than 50km/h for low beam driving and 60-70km/h for high beam driving, might not be nearly as ultra-conservative as Robins [1] suggested.

However, it would be unrealistic to lower the speed limits for night time driving to such low speed limits. It does suggest we should drive slowly for the sake of safety. But even at 15km/h, our results include a few trials where the participant failed to see the moose and would have rammed into it at the full 15km/h. Perhaps the most realistic conclusion is that no matter what error margin you place on human behaviour, you should still expect accidents. In the case of moose avoidance at the typical rural highway velocities, it may be better to concentrate our efforts towards the development of better driver assisting tools, such as the already promising early warning in-vehicle telematics under development. With these, the warning can be
made as salient as needed and can be delivered to the driver at twice the headway of human perception.

In the meantime, many things can be done to improve the current findings. For example, although it may be impractical for experimenters to have participants come for a single unexpected moose encounter, it may be possible to insert the moose decoy in other ongoing studies. Over time, data could trickle in over a longer period, hopefully resulting in more realistic data. Alternatively, within the framework of moose perception and avoidance research, experimentation times could be extended to the point where participants experience considerable boredom and forget their task at hand, resulting in reactions more like those expected in real world driving moose encounters.

In our particular case, since far side projection screens are less critical in solo night time driving, one of the rear visual channels could be sacrificed for the purpose of doubling the resolution of the front view screen. Also, the moose model could be textured more realistically. It may even be worth considering animating it, since anecdotal evidence suggests that although moose often freeze in action at the sight of an oncoming vehicle, they can sometimes dash from the roadsides, covering a 2-lane highway.

Other methods of validation should also be considered as on-road replication is typically very expensive, time consuming and impractical. Most notably, a recent attempt made use of self-reported real world driving data as a basis for comparison with simulated data with remarkable success [9]. This technique could easily be used as a means of providing a quick check prior to conducting larger studies.

Validation of driving simulators will continue until the day when participants who leave the driving research laboratory are convinced they really took the car out of the garage for a drive. Even with the perfectly immersive, accurate and realistic simulators, we will still have to validate the measures we take and the types of conclusions that we make.

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