MOOSE DETECTION DISTANCES ON HIGHWAYS AT NIGHT

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ABSTRACT: Moose-vehicle collisions are a serious concern in many areas of North America and Fennoscandia. In northwestern Ontario, more than 400 moose-vehicle collisions occur annually, and 26 fatal collisions have occurred over the last 10 years. To avoid colliding with a moose, a motorist must: (1) successfully see or detect the presence of the animal; (2) determine whether or not the moose poses a threat requiring evasive action; (3) determine what action, if necessary, is required; and (4) implement the action. Whereas perception-reaction times of motorists have been studied in detail, allowing calculations of post-detection distances travelled by a vehicle at different speeds, distances at which a moose can first be seen by a driver at night are unknown. We used a full-size moose decoy to determine the distances at which an animal could be detected at night when it was positioned on each shoulder and in the middle of a highway using high and low beam headlamp settings of different vehicles. Overall, we found the mean detection distance across all vehicle types, headlamp settings, and moose decoy locations to be 105 m (range: 23-210 m). Headlamp setting was a significant factor; on the low beam setting, mean detection distance was 74 m and on the high beam setting it was 137 m. Moose decoy location was also important; combining the data for both headlamp settings, mean detection distances were 89 m, 93 m, and 133 m for the left, right, and centre positions, respectively. There was no relationship between headlamp height of different vehicles and moose detection distance. Comparing our results with previously known perception-reaction times of motorists, we determined that drivers travelling at night in excess of about 70 km/h are very likely to be overdriving the illumination capabilities of their headlamps for moose encounters. For drivers using a low beam headlamp setting, the maximum safe speed drops to about 60 km/h and on high beam setting, rises to about 80-90 km/h. These results suggest that along highway corridors where collisions with motor vehicles present a serious threat to public safety and may have significant impacts on local moose populations, speed limits should be set no higher than 70 km/h at night.

ALCES VOL. 42: 75-87 (2006)

Key words: *Alces alces*, detection distance, moose-vehicle collisions, MVCs, Ontario, visibility distance

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Collisions between moose (*Alces alces*) and motor vehicles are a serious concern in many areas of North America and Fennoscandia (Grenier 1973, Child and Stuart 1987, Child et al. 1991, Del Frate and Spraker 1991, Lavsund and Sandegren 1991, McDonald 1991, Oosenbrug et al. 1991, Schwartz and Bartley 1991, Child 1998, Joyce and Mahoney 2001, Lavsund et al. 2003, Seiler 2003, Timmermann and Rodgers 2005). At least 3,000 moose-vehicle collisions occur annually across North America (Child 1998); a highly conservative estimate since many accidents are not reported and most jurisdictions do not maintain accurate records (Child and Stuart 1987, Romin and Bissonette 1996, Sullivan and Messmer 2003, Transport Canada 2003). In northwestern Ontario alone, more than 400 moose-vehicle collisions were reported in 2002 (Staff Sergeant R. Beatty, Ontario Provincial Police, unpublished data 2004). These accidents injure, cripple, and kill considerable numbers of moose and can result in substantial property damage, human injury, and death; 20% of moose-vehicle collisions result in injuries with a 0.5% human fatality rate (Garrett and Conway 1999, Transport Canada 2003) and 26 human fatalities have resulted from collisions between vehicles and wildlife in northwestern Ontario over the last 10 years (Transport Canada 2003). The economic costs associated with moose-vehicle collisions include the material loss of vehicles, human injuries (ambulances, medical expenses, disability payments), human fatalities (life insurance, funeral expenses), call-out costs for police, veterinarians, and wildlife officials to deal with injured or dead moose, loss of meat and hunting opportunities, and business/societal costs of transportation delays (Seiler 2003, Timmermann and Rodgers 2005); at an average cost of CDN$4,500 per accident, including only vehicle damage and loss of meat value (Transport Canada 2003), the economic cost of reported moose-vehicle collisions is at least CDN$13,500,000 annually in North America.

Notwithstanding the potentially severe social and economic consequences of moose-vehicle collisions, these accidents can directly reduce moose population numbers locally or affect their productivity through alteration of sex and age ratios (Leopold 1933, Peterson 1955, Child 1998). In North America, moose mortalities resulting from collisions with vehicles correspond to about 4% of the annual allowable moose harvest, ranging from 0.3% in Manitoba to 196% (i.e., almost double the annual allowable harvest) in New Hampshire (Child 1998). Of 1,673 non-hunting moose mortalities recorded in northeastern Ontario over a 10-year period (1983-1991), 48% were attributed to motor-vehicle collisions; total incidental fatalities were almost double the combined losses to predation, subsistence harvest, poachers, and unknown causes (Child 1998). Clearly, there is good reason to consider the importance of moose-vehicle collisions in the development of sustainable moose population management programs and the setting of harvest objectives. Moreover, in areas where collisions with motor vehicles may have significant impacts on local moose populations, additional management actions are necessary to reduce the risks and costs of accidents.

A wide range of measures to reduce moose-vehicle collisions have been applied in various jurisdictions, with greater or lesser degrees of success, including; public education programs (e.g., pamphlets, posters, bumper stickers, newspaper advertising, radio and television notices), habitat modification to make roadways unattractive to moose and/or create high quality habitat in areas away from highway corridors, vegetation management to widen transportation routes and improve roadside visibility, adjustments of travel speed, improved lighting and signage, construction of physical structures (i.e., fencing, one-way gates, underpasses/overpasses), reflective mirrors and ultrasonic warning devices, ultraviolet (UV) headlamps, and, more recently, development of intelligent transportation systems (e.g., microwave radar, infrared images, fibre-optic grating, seismic sensors, thermal imaging) (Child 1998, Forman et al. 2003, JHWF 2003, Transport Canada 2003, Timmermann and Rodgers 2005). Of these, properly maintained fencing appears to be the most effective, but is impractical for extensive use because of high installation and maintenance costs (Lavsund and Sandegren 1991, Schwartz and Bartley 1991, Forman et al. 2003, JHWF 2003, Transport Canada 2003). Alternatively, a combination of vegetation management and traffic controls may provide a more practical long-term solution (Schwartz and Bartley 1991, Child 1998). However, management of vegetation may only provide temporary reductions in moose-vehicle collisions and may actually increase the risk of accidents if not maintained to limit the growth of early seral vegetation that may attract moose to highway corridors (Child 1998). Regulating vehicle speed, on the other hand, is inexpensive to implement and maintain relative to other measures.

Most moose-vehicle collisions occur between 1800-0200 hrs on straight and relatively flat stretches of 2-lane highways with elevated speed limits and traffic volumes, particularly where visibility is limited by encroaching vegetation (Stuart 1984, Child et al. 1991, Del Frate and Spraker 1991, Forman et al. 2003, JHWF 2003). To avoid an accident, drivers must successfully: (1) detect the presence of a moose; (2) determine whether or not the moose presents, or is likely to present, a threat that will require an evasive response; (3) determine what action (e.g., steering or braking), if any, is required to avoid a collision; and (4) if necessary, implement the chosen action (Olson 1996, Olson and Farber 2003). Some amount of time will pass from when a moose is first detected to when an evasive action is completed, during which the vehicle will cover some or all of the distance between the vehicle and the moose. How much of that distance will be traversed depends on: (1) the distance at which the moose is first detected; (2) how fast the vehicle is travelling; (3) how long it takes the driver to perceive and react; and (4) how long it takes the driver to complete an evasive manoeuvre. Whereas perception-reaction time (Olson 1996, Olson and Farber 2003) and the time and distance required to brake a vehicle to a complete stop from a given travel speed (Russell 1999) have been documented, no data are available pertaining to actual driver detection distances for moose at night. The intent of this study was to determine the distance at which a driver operating a vehicle on a straight and relatively flat stretch of highway at night could first detect the presence of a moose. We also attempted to ascertain whether or not detection distance was related to variation in headlamp heights of different vehicle types. This information was then used in comparisons with previously published perception-reaction times and braking data to estimate travel speeds that may be implemented along highway corridors to reduce the risks and costs of accidents between motor vehicles and moose.

STUDY AREA

The study was conducted on an 800 m straight and level section of Highway 527 (Fig. 1), approximately 9.4 km north of its intersection with Highway 11/17, about 20 km northwest of Thunder Bay, Ontario, Canada. The 2-lane segment of highway used in the tests was asphalt covered with opposing lanes separated by a broken yellow line and roadway edges demarcated by 3m-wide gravel/dirt shoulders. The highway corridor cuts through natural forest (primarily balsam poplar, *Populus balsamifera*, trembling aspen, *P. tremuloides*, and white spruce, *Picea glauca*) with rock outcroppings. Vegetation on the west side of the highway was cleared back from the shoulder of the roadway to a distance of about 7 m and on the east side to almost 20 m. The section of highway used was intersected by several game trails showing recent evidence (i.e., tracks, droppings) of use by moose, thereby providing a realistic setting for the study.

A small clearing (N48º33’46”, W89º08’08”) on the west side of Highway

Figure 1. Daytime view, looking north, of the 800 m section of Highway 527, approximately 20 km northwest of Thunder Bay, Ontario, Canada, used in determinations of moose detection distances on a highway at night.

527, about 8.3 km north of its intersection with Highway 11/17 and 1 km south of the test site, was used as a staging area for drivers and vehicles. The staging area was blocked from view of the test segment by an almost 90-degree bend in the highway, thick forest, and rolling topography.

METHODS

Moose Surrogate

As it would have been impractical to control the behaviour of a live moose for the purpose of this study, a decoy was employed as a surrogate. The surrogate was a life-sized bull moose decoy constructed from foam, covered with real moose hide, and fitted with real antlers. The moose-hide covering was critical in simulating the luminance properties of a moose at night.

The moose surrogate was located about 600 m from the start of the test section of the highway, and just north of an existing natural game trail. During the trials, the moose surrogate was set up on one of the shoulders or in the centre of the highway and always faced west.

Drivers

The test subjects in this study consisted of 14 drivers from the local geographic area who ranged in age from 20 to 55 yrs. The mean and median ages of the tested drivers were 38 and 40 yrs, respectively. Four subjects were female, 10 were male. Three subjects required no corrective eyewear while driving, 3 wore contact lenses, and 8 wore eyeglasses while driving.

Vehicles and Headlamp Heights

Seven vehicle types were used in this study (Table 1). The vehicles were chosen to reflect the general population of North American highway motor vehicles and represented a variety of standard headlamp types and heights above ground (measured to the middle of the headlamp on each vehicle). The only common vehicle type not included in the test fleet was a bus. However, the highway tractor was a cab-over-engine type with a flat front surface similar to that of a highway bus. The headlamps of all test vehicles were checked for proper alignment prior to the trials.

Test Conditions

At the time of the tests (2300-0430 hrs) starting on June 22, 2004, skies were clear, with a quarter moon that set at about 0100 hrs. It rained briefly shortly before the trials began and the road was still damp in sections. As a result, when the air cooled through the night from +5ºC at the beginning of the trials to -4ºC at their conclusion, a sporadic low rolling fog condition was observed throughout the test area. The section of road near the moose surrogate target, however, was clear during all trials and the pavement was dry for most of the tests.

During the tests, the highway was closed to all traffic not involved in the study, from the staging area to approximately 2 km further

Table 1. Headlamp characteristics of test vehicles used in determinations of moose detection distances on a highway at night.

Vehicle type	Year	Make	Model	Headlamp type	Headlamp height (cm)
Motorcycle	2002	Yamaha	V-Star 1100 Classic	Sealed beam	87
Highway tractor	1998	International	90S	Halogen	103
Minivan	2004	Dodge	Caravan	Halogen	74
Automobile (halogen)	2003	Ford	Focus	Halogen	65
Automobile (HID)	2004	Kia	Amanti	Xenon HID	71
Pick-up truck	2004	Ford	F-150	Halogen	98
Sport utility vehicle	1995	Jeep	Grand Cherokee	Halogen	85

north of the test area. This allowed test vehicles to move safely at slow speeds and prevented any effects on visibility that might be caused by the headlamps of oncoming traffic.

Test Procedure

In total, there were 42 test trials. Each driver was randomly assigned to a single vehicle (2 drivers per vehicle type) and to a single headlamp setting condition (high beam or low beam) for that vehicle, with the exception of 4 subjects, who by virtue of requiring specialized licensing to operate the commercial tractor or motorcycle, were assigned to the appropriate vehicle type. Each of these 4 drivers, however, was assigned either the high beam or low beam condition on a random basis. Thus, each subject drove one of the test vehicles on either the high beam setting or the low beam setting, but not both. Each of the 14 subjects drove their assigned test vehicle 3 times, one for each moose location (left shoulder, centre of driving lane, and right shoulder). The order of the trials with respect to driver, vehicle type, and headlamp setting was randomly determined.

On each trial, the test subject was asked to drive slowly through the test area using the assigned high beam or low beam headlamp setting until the moose surrogate was visually detected, then bring the vehicle to a full and immediate stop. One of the investigators accompanied each driver on at least the first trial to ensure that the subjects were able to judge and maintain an approach speed of about 10-15 km/h without watching the speedometer.

Once the vehicle was fully stopped, luminance readings for the moose surrogate target and background were taken from the front of the vehicle with a Hagner Universal Photometer Model S2 (B. Hagner AB, Solna, Sweden) capable of detecting light levels as low as 0-1 lux with an accuracy of ± 3%. However, in spite of the sensitivity of the photometer employed, the light reflected back from the moose surrogate to the photometer placed at the front of the vehicle was so low (< 1 lux) that these measurements were abandoned after the first few trials. The linear distance from the moose to the front surface of the vehicle was measured with a Laser Technology Impulse Laser Model 200XL (Laser Technology, Inc., Centennial, Colorado, USA) that can measure up to 2,200 m with a typical accuracy of ± 1 m and an accuracy of ± 2 m at the maximum distance. Following these measurements, the test subject turned the vehicle around and returned to the staging area.

Statistical Analysis

The dependent variable in this study, detection distance, was operationally defined as the linear distance, to the nearest meter, between the moose target and the front surface of the vehicle at the point where the driver stopped the vehicle after visually detecting the presence of the moose surrogate on the highway. In addition to presenting the means (± SD) and medians (range) of these data from the trials, results are expressed in terms of the 15th percentiles to denote the visibility distances at which most drivers would be able to detect the presence of a moose on a highway under these test conditions. In this type of research, "most" is usually defined as those drivers within the 85th percentile, thereby excluding the 15% of tested subjects with the shortest detection distances for a particular set of conditions (Olson and Farber 2003).

The study employed a 2 x 3 factorial design with repeated measures of detection distance on the second independent variable. The first independent variable was headlamp setting, for which 2 levels were established: high beam and low beam. The second independent variable was moose location, for which there were 3 levels: left side of the highway, centre of the driving lane, and right side of the highway. Each subject experienced all 3 moose location conditions, producing repeated measures on the moose location variable. Subsequently, a 2 x 3 factorial ANOVA (SPSS 13.0, SPSS Inc., Chicago, Illinois, USA) was used to analyze the detection distance data.

Vehicle type was not directly analysed as a variable of interest because of limited sample sizes and because it would have been confounded with other variables such as driver, type of headlamp system, etc. We were also unable to determine any relationships between detection distances and the types of headlamp systems (i.e., sealed beam vs halogen vs high intensity discharge) of different vehicles because of unequal and insufficient sample sizes for some of these systems. However, simple linear regression (SPSS 13.0, SPSS Inc., Chicago, Illinois, USA) was used to explore the relationship between detection distances and variation in headlamp heights among different vehicle types.

Distances required to bring a vehicle to a safe stop from selected speeds were calculated from perception-reaction times and braking data measured in previous studies (Russell 1999, Olson and Farber 2003). These required stopping distances were compared to fully adjusted detection distances of test drivers to determine whether or not there would be sufficient distance for real-world drivers to avoid a collision when travelling on a straight and relatively flat stretch of highway at night over a range of specific speeds (50-120 km/h).

Adjustment of Detection Distances for Test Drivers

Before data obtained in this study could be used in comparisons with drivers in the real world, measured detection distances needed to be adjusted for the perception-reaction and stopping distances of the test drivers, as well as their expectancy of encountering the moose surrogate. From the time a driver detects the presence of an unexpected object-of-interest, to the time the driver is able to initiate some evasive response, perception-reaction will require about 0.50 – 1.25 secs for most (i.e., 85%) drivers (Olson and Farber 2003). The test subjects in this study knew what to expect; they knew that they would encounter a moose target and they knew exactly how to react. Thus, the minimum perception-reaction time of 0.5 secs is appropriate for test subjects. Since the speed of the vehicle during each trial was restricted to 15 km/h (4.16 m/s) or less, it would have travelled as much as 2.08 m during the time it took each test driver to react to the moose surrogate and apply the brakes. At a deceleration rate of 2.94 m/s/s (Russell 1999), an additional distance of 2.95 m would have been required to brake the vehicle to a comfortable but decisive stop from a speed of 15 km/h (see Equation (1) below). Accordingly, the measured detection distances were adjusted by adding 5 m to account for the perception-reaction processes and braking activities of test drivers.

In the real world, drivers are not likely to be as sensitized, alert, and decisive as were the test subjects in this study. Real drivers would most likely require more time to actually detect a hazard and therefore be closer to the hazard when detection is complete. Previous night-time visibility studies suggest an additional 0.5 secs is a reasonable adjustment to the expected detection time for real drivers at night compared to experimental test drivers (Olson and Sivak 1986). The additional distance required for detection of a hazard by drivers in the real world is subsequently calculated as a function of vehicle speed; e.g., for a vehicle travelling at 50 km/h (13.9 m/s), we estimated a driver unaware of the hazard would be 6.95 m closer to the moose surrogate when it was detected than one of the test drivers. These distances were calculated for real drivers travelling at a range of different speeds (50-120 km/h) and deducted from the detection distances previously adjusted to account for the perception-reaction processes and braking activities of test drivers.

Calculation of Stopping Distances for Real Drivers

Whereas a minimum perception-reaction time of 0.5 secs may be suitable for test subjects expecting to encounter a hazard on the highway at night, as above, a maximum perception-reaction time of 1.25 secs, as measured in previous studies (Olson and Farber 2003), is more appropriate for most (i.e., 85%) real-world drivers. Thus, from the time that a moose is detected on a highway at night, it is expected that all but the 15% of drivers with the slowest perception-reaction times will be able to initiate an evasive manoeuvre within 1.25 secs. The distance travelled by a vehicle during the driver's perception and reaction is speed dependent and is simply the arithmetic product of vehicle speed (m/s) and the perception-reaction time of 1.25 secs (Table 2).

In this study, we consider only braking to a stop as the evasive action. Some other action such as steering, a speed reduction, or sounding a warning with the horn would be expected to take some lesser amount of time to accomplish than would braking to a complete stop, so our calculations account for the maximum amount of time taken to achieve an evasive response. The following equation, modified from Russell (1999) to directly incorporate the gravitational rate of acceleration (9.81 m/s/s), was used to calculate the distance required to brake a vehicle to a complete stop from a particular speed:

$$d = \frac{S^2}{25.9f} \qquad (1)$$

where, d = distance required to stop (m); S = vehicle speed (km/h); f = deceleration rate (m/s/s). Assuming that a vehicle is braked hard with a deceleration rate of 6.87 m/s/s (equivalent to a vehicle with all wheels locked and sliding on a well-travelled dry asphalt surface; Russell 1999), the distances required to bring the vehicle to a complete stop from selected speeds are given in Table 2.

RESULTS

Main effects on detection distance were found for both headlamp setting (F = 35.77; df = 1, 12; P = 0.00006) and moose location (F = 6.56; df = 2, 16; P = 0.008), but there was no statistically significant interaction between these two variables.

Headlamp Setting

The mean (± SD) and median (range) moose detection distances for the low beam headlamp setting were 74 m (± 29 m) and 75 m (23 – 124 m), respectively. The 15th percentile value was 47 m, indicating that most (85%) of the tested subjects were able to detect the presence of the moose from 47 m away or greater. The mean and median distances for the high beam headlamp condition were 137 m (± 51 m) and 147 m (28 – 210 m), respectively, with a 15th percentile value of 74 m.

Moose Location

The moose surrogate was set up at 3 locations on the highway. When data were combined for high and low beam headlamp conditions, the mean (± SD) and median (range) detection distances, respectively, for these moose locations were 89 m (± 55 m) and 64 m (23 – 189 m) for the left shoulder; 93 m (± 37 m) and 84 m (28 – 172 m) for the right shoulder; and 133 m (± 54 m) and 124 m (40 – 210 m) for the centre of the

Table 2. Distances travelled by a vehicle during a driver's perception-reaction time of 1.25 seconds (Olson and Farber 2003) and while braking a vehicle to a complete stop at a deceleration rate of 6.87 m/s/s (equation (1); Russell 1999) over a range of selected speeds.

		Vehicle Speed (km/h)							
		50	60	70	80	90	100	110	120
Distance travelled (m)	Perception-reaction	17	21	24	28	31	35	38	42
	Braking	14	20	28	36	46	56	68	81

driving lane. The 15th percentile values for the 3 moose location conditions were 46 m, 73 m, and 79 m for the left, right, and centre positions, respectively.

Vehicle Type and Headlamp Height

There was no linear relationship between headlamp height of different vehicles and moose detection distance on either the low ($r = 0.001$; $F = 0.000$, df = 1, 19, $P = 0.997$) or high beam setting ($r = 0.167$; $F = 0.543$, df = 1, 19, $P = 0.470$). Nor was there any relationship between headlamp height and moose detection distance when the surrogate was located on the left ($r = 0.018$; $F = 0.004$, df = 1, 12, $P = 0.951$), right ($r = 0.360$; $F = 1.783$, df = 1, 12, $P = 0.207$), or centre ($r = 0.014$; $F = 0.002$, df = 1, 12, $P = 0.962$) of the driving lane.

Total Data Set

To generalize our results for subsequent comparisons with required stopping distances, we combined the detection data across all vehicle types, headlamp settings, and moose location conditions, which produced mean and median detection distances of 105 m (± 52 m) and 99 m (23 – 210 m), respectively, with a 15th percentile value of 54 m.

Adjusted Detection Distances for Test Drivers

Although moose location was found to be a significant determinant of detection distance, drivers in the real world obviously cannot predict or control the position of a live moose on a highway. On the other hand, real drivers can control the headlamp setting of their vehicle. Thus, adjustments were made to the 15th percentile detection distances of test drivers for the low and high beam headlamp setting conditions, as well as the total data set, for vehicles travelling at different speeds.

As previously outlined, detection distances were first adjusted by adding 5 m to account for the perception-reaction processes and braking activities of test drivers. So, for example, the 15th percentile value for moose detection distance in the total data set is increased to 59 m; for low beam and high beam settings, values are adjusted to 52 m and 79 m, respectively. Next, adjusted test values were reduced by the additional distance required for detection of a hazard by unaware drivers in the real world travelling at a particular speed; i.e., the distance travelled in an additional 0.5 secs at a given speed. Thus, for a vehicle travelling at 50 km/h, test values were reduced by 7 m and the fully adjusted 15th percentile values were 45m for the low beam setting, 72 m for the high beam setting, and 52 m for the combined data set (Table 3). Fully adjusted moose detection distances estimated for real-world drivers travelling at other selected speeds are given in Table 3.

For comparisons with fully adjusted detection distances of test drivers, distances travelled by a vehicle during a real-world driver's estimated perception-reaction time of 1.25 secs were added to braking distances (Table 2) to estimate the total distances required, following detection of a moose, to bring a vehicle to a safe stop from selected speeds (Table 3).

DISCUSSION

When the distance required to perceive a moose on the road, react, and stop a vehicle exceeds the available detection distance at a given speed (Table 3), then a collision will likely result. Clearly, the faster one travels above that speed, the greater the impact and potential consequences of a collision. Conversely, if the moose detection distance exceeds that required by a driver to perceive, react, and bring a vehicle to a safe stop from a given speed, then it is expected that a moose-vehicle collision can be avoided. Based on the total data set, which implies nothing specific is known about the situation (i.e., headlamp setting, moose location, vehicle type, driver, etc.), the required stopping distance exceeds

Table 3. Comparison of calculated distances required for drivers to perceive, react, and brake a vehicle to a complete stop from selected speeds (sum of distances travelled during a perception-reaction time of 1.25 secs and while braking at a deceleration rate of 6.87 m/s/s from a given speed; Table 2) with distances available to complete the evasive manoeuvre based on moose detection distances adjusted for the perception-reaction processes and braking distances of test drivers, as well as their expectancy, while travelling on a highway at night using low or high beam headlamp settings (*n* = number of trials). When the distance required exceeds the available detection distance at a given speed, then a moose-vehicle collision will likely result.

		Vehicle Speed (km/h)							
		50	60	70	80	90	100	110	120
Required distance (m)		31	41	52	64	77	91	106	123
Available distance (m)	Low beam (n = 21)	45	44	42	41	39	38	37	35
	High beam (n = 21)	72	71	69	68	66	65	64	62
	Total (n = 42)	52	51	49	48	46	45	44	42

the available distance at speeds of 70 km/h or more (Table 3). Thus, drivers can avoid a moose-vehicle collision 85% of the time by travelling at less than 70 km/h on a highway at night. In most jurisdictions, however, it is recommended that drivers use the high beam headlamp setting on their vehicle when travelling on highways at night; e.g., in Ontario, drivers are expected to use the high beam headlamp setting at night whenever possible and switch to the low beam setting within 150 m of an oncoming vehicle or when following a vehicle within 60 m. In the high beam condition, the required detection distance to perceive, react, and stop a vehicle exceeds the available distance at speeds of 80-90 km/h (Table 3). On the low beam setting, the required detection distance exceeds the available detection distance at speeds of 60-70 km/h. Coincidentally, the speed limit on the section of highway where the visibility trials were conducted is posted as 80 km/h, which is in agreement with the required detection distance on the high beam setting described in this study but too high for the low beam condition or combined data.

Although moose location is unpredictable in real-world situations, we found that visibility distance was affected by the location of the moose surrogate on the highway. Based on the 15th percentile values, the surrogate was detected further away when placed in the centre of the driving lane (79 m) or on the right shoulder (73 m), than on the left shoulder of the highway (46 m). This is consistent with Transport Canada (2001) regulations that ensure headlamps are aligned so the light does not project up or towards the left into oncoming traffic when on the low beam setting; high beam headlamps are aimed so the brightest spot is centred at the same height as the headlamp. Thus, reduced detection distances when the moose surrogate was located on the left shoulder of the highway were largely the result of measurements made on the low beam headlamp setting.

The lack of a relationship between headlamp heights of different vehicles and moose detection distance, regardless of headlamp setting or the location of the moose surrogate on the highway, was also likely the result of headlamp alignment according to Transport Canada (2001) regulations. Although we expected detection distance might increase with height of the headlamps above the roadway surface, any potential improvement afforded to vehicle types with higher headlamps was negated by angling them downward to prevent projection into oncoming traffic when on the low beam setting; this downward projection would also affect the aim of headlamps on the high beam setting.

The validity of generalizing the findings of this study to real life depends on the degree to which the subjects, conditions, and procedures employed, correspond to those that would be expected in the real world. The vehicles used in the trials were chosen deliberately to reflect a modern fleet that would likely be encountered on Canadian roadways. The subjects were real drivers from the same geographic locale as the study and a real section of highway, which is normally frequented by moose, was used for the tests. The moose surrogate was as lifelike as could be managed short of using a live moose. All in all, it is likely that the conditions reproduced in the investigation procedures were as close an approximation to what a real driver would face, as would be possible in a study such as this. Nonetheless, there are a multitude of factors that might diminish the ability of drivers in the real world to detect, perceive, react, and avoid colliding with a moose, or any other hazard for that matter, on a highway at night.

The drivers in this study lived in a region in which moose encounters are frequent and many of them had experienced moose encounters on the roadway in the past. As such, this group of drivers, as a whole, could be considered ideal. Many of these subjects were able to identify the presence of the surrogate moose target when only the lighter coloured lower legs were illuminated by the headlamps. An inexperienced motorist with regard to moose encounters might require additional detection time and therefore be closer to a moose upon completion of detection, leaving less room to react to and stop for the hazard.

Additionally, data collected in this study are reflective of what one would expect from sober, alert, and unusually attentive drivers. A driver who is fatigued, momentarily distracted by a passenger or in-vehicle device, or otherwise momentarily inattentive, would be expected to be closer to the moose at the point of detection than has been determined herein.

These test trials involved a static target. The moose surrogate was placed on the roadway and "stood still" for each trial. Live moose are highly unpredictable and often in motion during encounters with vehicles; they can enter the roadway quite suddenly. Through their movement, the light leg colours, vulva patch, and light reflecting from the eyes of live moose may be easier for motorists to detect than the stationary moose surrogate used in these trials. While a moose in motion might provide additional visual cues that assist in detection, it is most likely that real drivers would nonetheless face more complex and challenging avoidance situations in moose-vehicle encounters than did the test subjects in this investigation.

The results of this study must also be considered preliminary because practical constraints restricted the variables examined to headlamp height, setting, and moose location. Vehicle types varied, but not systematically. Future endeavours ought to employ sufficient numbers of subjects to permit independent, rather than repeated measures across the moose location variable. Ideally, sample sizes would be sufficiently large to permit unique detection distance summary data for headlamp illumination, moose location, vehicle type, and headlamp type conditions, since these characteristics are normally fairly easy to ascertain for any specific real-world moose-vehicle collision. Of course, these trials should be conducted under a variety of weather conditions at different times of the year and on various road surfaces. While luminance values were not a critical measure of interest in this study, it might be useful in the future to ascertain the luminance differences between the moose surrogate employed in this study and that expected from a live animal. It is possible that the sheen from a clean coat or the drab appearance of a wet and dirty coat of a live animal could present visual cues for real drivers that are different from those inherent in the decoy used in the present investigation. Follow-up investigations should also consider ways to test differences in detection distances for moose at night between stationary and moving targets. In the present endeavour the target remained stationary during each trial and only its location across the highway was varied. A moving moose might present a motorist with a different set of visual and cognitive challenges.

MANAGEMENT IMPLICATIONS

Our results (Table 3) suggest that most drivers travelling at speeds in excess of about 70 km/h on a highway at night are very likely to be overdriving the illumination capabilities of their headlamps for moose encounters. Even when the high beam headlamp setting is used, travelling at more than 80 km/h could be hazardous. These results are consistent with previous studies that have found an increase in moose-vehicle collisions when travel speed exceeds 80-90 km/h (Stuart 1984, Forman et al. 2003). Thus, it would be prudent to suggest that along highway corridors where collisions with motor vehicles present a serious threat to public safety and may have significant impacts on local moose populations, speed limits should be set no higher than 70 km/h.

Unfortunately, lowering speed limits is not generally favoured or supported by motorists or road authorities (Lavsund and Sandegren 1991). Speed limit signs do little to change driver behaviour and motorists travel at speeds determined by their perception of roadway conditions and traffic volume rather than posted speed limits (Romin and Bissonette 1996, Putman 1997). Thus, it may be more acceptable to recommend diurnal or seasonal speed limit reductions (JHWF 2003). For example, approximately 70% of wildlife-vehicle collisions in northwestern Ontario occur between June and October (Staff Sergeant R. Beatty, Ontario Provincial Police, unpublished data 2004), suggesting a reduction of speed limits during that period. Both Texas and Montana have lower speed limits at night (105 km/h) than during the day (120 or 110 km/h) but these appear to be too high, according to the present study, to effectively reduce wildlife-vehicle collisions, and only Montana has moose. Based on previous studies (Stuart 1984, Forman et al. 2003) and our results, it would be more reasonable to recommend speed limits of 80 km/h during the day and 70 km/h at night. These recommended speeds will not prevent moose-vehicle collisions from occurring but could significantly reduce the numbers of incidents, particularly if combined with other mitigating measures such as increased fines for speeding through areas where collisions with motor vehicles present a serious threat to public safety (similar to higher fines issued within construction zones), rumble strips that may get a driver's attention and remind them to slow down, automated radar speed detectors that notify drivers when they may be at risk, and public service announcements of where, when, and why speed reductions are being implemented (JHWF 2003).

ACKNOWLEDGEMENTS

The authors would like to thank members of the Ontario Provincial Police, especially Staff Sergeant Bob Beatty and Rod Brown, and members of the Ministry of Transportation of Ontario, especially Tom Marinis, without whose support and participation the undertaking of this study would not have been possible. We are grateful to Manitoba Conservation, particularly Rob Dean, Cory Mischuk, and Vince Crichton for arranging the loan of their moose decoy. A special thanks to Halfway Motors in Thunder Bay, Ontario, for the loan of the xenon lamp equipped test vehicle and to Brian and Jack McCrury for the use of their highway tractor. A special debt of gratitude is expressed to the many volunteer drivers who suffered a long cold night to complete the test trials. Finally, we thank Brian McLaren, Brad Allison, and 2 anonymous reviewers for their comments and suggestions on an earlier version of this manuscript.

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