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Driving behaviour responses to a moose encounter, automatic speed camera, wildlife warning sign and radio message determined in a factorial simulator study

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ABSTRACT

In a driving simulator study, driving behaviour responses (speed and deceleration) to encountering a moose, automatic speed camera, wildlife warning sign and radio message, with or without a wildlife fence and in dense forest or open landscape, were analysed. The study consisted of a factorial experiment that examined responses to factors singly and in combination over 9-km road stretches driven eight times by 25 participants (10 men, 15 women). The aims were to: determine the most effective animal–vehicle collision (AVC) countermeasures in reducing vehicle speed and test whether these are more effective in combination for reducing vehicle speed; identify the most effective countermeasures on encountering moose; and determine whether the driving responses to AVC countermeasures are affected by the presence of wildlife fences and landscape characteristics. The AVC countermeasures that proved most effective in reducing vehicle speed were a wildlife warning sign and radio message, while automatic speed cameras had a speed-increasing effect. There were no statistically significant interactions between different countermeasures and moose encounters. However, there was a tendency for a stronger speed-reducing effect from the radio message warning and from a combination of a radio message and wildlife warning sign in velocity profiles covering longer driving distances than the statistical tests. Encountering a moose during the drive had the overall strongest speed-reducing effect and gave the strongest deceleration, indicating that moose decoys or moose artwork might be useful as speed-reducing countermeasures. Furthermore, drivers reduced speed earlier on encountering a moose in open landscape and had lower velocity when driving past it. The presence of a wildlife fence on encountering the moose resulted in smaller deceleration.

1. Introduction

Animal–vehicle collisions (AVCs) are a growing problem in Sweden and worldwide (*e.g.* Groot Bruinderink and Hazebroek, 1996; Putman, 1997; Jägerbrand, 2014). AVCs are a major societal and ecological concern, since they increase with increasing traffic volume and road density and when human activities encroach on wildlife habitats and cause habitat fragmentation. In addition, AVCs are associated with substantial economic, ecological and medical costs. For example, in Sweden roe deer–vehicle collisions alone cost an estimated 33 million Euro in 2012 (Jägerbrand, 2014), while in Germany such collisions cause approximately 50 fatalities per year (Hothorn et al., 2012).

AVCs and their probability of occurrence in relation to different factors in the environment and infrastructure have been examined post-event in many studies (Puglisi et al., 1974; Allen and McCullough, 1976; Case, 1978; Seiler, 2004, 2005; Gunson et al., 2009, 2011; Glista et al., 2009; Hothorn et al., 2012; Cserkész et al., 2013). These studies report some correlations between AVCs and *e.g.* wildlife population density, traffic volume, vehicle speed, different road characteristics (*e.g.* road width, vegetation clearance, and bridges), character of the surrounding landscape (*e.g.* distance to urban areas, forests, and fields) and wildlife fences. It shall be acknowledged that these results are due to correlated variables where certain types of roads (*e.g.* rural) may result in increased AVCs due to more animal crossings.

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Although wildlife fences are the most effective and most generally accepted AVC countermeasure, they do not completely eliminate AVCs, since animals can still manage to get through and enter the road area (Cserkész et al., 2013). Moreover, wildlife fences are not considered applicable everywhere, as fencing isolates wildlife populations, causing a higher degree of fragmentation. Fences are also associated with high installation and maintenance costs.

Unfortunately, examining patterns of AVCs after the event provides little, if any, substantial information regarding driving behaviour, although this must be considered one of the major contributing factors to AVCs. Despite being repeatedly identified as a crucial factor that influences the probability of AVCs (Hedlund et al., 2004; Putman et al., 2004; Knapp, 2005; Neumann et al., 2012), motorist behaviour before an AVC has generally rendered few studies (*cf.* Åberg, 1981).

The way in which drivers normally scan the road ahead seems to be ineffective for detecting moose (Åberg, 1981). In fact, AVC risks may be largely due to driving behaviour, rather than to animal behaviour around roads (Neumann et al., 2012). Driving behaviour can be viewed as the outcome of driver experience in interaction with their reactions to different driving circumstances. Available AVC countermeasures for affecting driving behaviour can be divided into information, knowledge-based, in-vehicle and outside-vehicle methods. One of the objectives of these measures is to reduce vehicle speed and others to increase the driver's ability to identify, react and avoid hitting the animal.

The effectiveness of information or knowledge-based methods in reducing AVCs is largely unknown (Mastro et al., 2008), but such methods are very often implemented. In-vehicle methods include, *e.g.* techniques such as infrared thermal imaging or messages to alert drivers about the presence of animals on the road (Rigney and Mitchell, 2000; Hirota et al., 2004; Mastro et al., 2008). However, to the best of our knowledge, in-vehicle methods have not been studied under controlled conditions for their effectiveness in preventing AVCs. Outside-vehicle methods include, *e.g.* warning signs, lower speed limits, road lighting and vegetation clearance. The effectiveness of road lighting and vegetation clearance has been questioned, but in several studies different kinds of warning signs (*e.g.* enhanced caution signs, temporary signs, dynamic or variable message signs (VMS) and animal-activated warning signs) have been shown to reduce vehicle speed (Hardy et al., 2006; Mastro et al., 2010). However, these studies have mainly been performed under uncontrolled field conditions. We want to stress that while Stanley et al. (2006) performed a driving simulator study where wildlife advisories (conventional signs and VMS) were shown to reduce vehicle speed, their work also showed that standard deer warning signs did not. Consequently, it appears that AVC countermeasures may have the potential to reduce speed more strongly when applied in combination, but they are rarely implemented in this way. Moreover, some studies question the long-term effectiveness of signs, as drivers become accustomed to them over time (Pojar et al., 1975). Most studies on animal warning signs to date have been conducted in North America and Australia. With few exceptions such as Al-Ghamdi and AlGadhi (2004) there is a lack of knowledge on the effectiveness of the standardised triangular animal warning signs that are used outside North America and Australia such as, *e.g.* Europe, Asia and the many countries worldwide that have ratified the Vienna Convention on Road Signs and Signals (UN, 1968). Because the signs differ in colour, shape, size and design of the animal symbols, it is unknown whether driver responses are similar in different countries. Finally, the use of driving simulators seem to be uncommon in AVC research.

This study examined driver behaviour responses in terms of reduced vehicle speed to in-vehicle (radio message warning) and outside-vehicle methods (a static wildlife warning sign and an automatic speed camera) alone and on encountering a moose. The focus was on vehicle speed, since it is usually controlled by speed limits and traffic enforcement signs, but it is unknown whether such measures are more or less effective than in-vehicle methods or other outside-vehicle methods. However, reducing vehicle speed is one important factor for improving traffic safety (Godley et al., 2002; Nilsson, 2004; Elvik and Vaa, 2008), and, according to Seiler (2005) and Langbein et al. (2011), speed is also a factor that affect the number of AVCs and their outcome in terms of the severity of human injuries. Furthermore, Seiler (2005) stress that reducing speed was the most effective way of reducing moose collisions for any given traffic volume.

In this study, we also examined whether the presence of wildlife fences or dense forest, compared with open landscape, has an effect on driving behaviour. We hypothesised that wildlife fences cause drivers to feel safe, fail to reduce their speed and underestimate the risk of AVCs. Forest-dominated landscape has been shown to have a speed-reducing effect (Antonson et al., 2009).

The following research questions were studied:

- What AVC countermeasures are most effective in reducing vehicle speed?
- Are AVC countermeasures more effective in combination than singly for reducing vehicle speed?
- What countermeasures are most effective on encountering a moose while driving?
- Are driving responses to AVC countermeasures affected by the presence of wildlife fences or dense forest in the landscape?

2. Methods

The study was conducted in a driving simulator, which is a common approach for studying driving behaviour and responses. The use of driving simulators has sometimes been criticised for not accurately reflecting the speed levels detected in on-road situations. However, since the driving simulator presents human-made animated scenarios that are implemented under simulated driving conditions, unwanted external factors are absent and research on driving behaviour can be conducted using rigorous experimental designs and tested statistically and replicated. For the purposes of the present study on the effectiveness of AVC countermeasures, using a driving simulator had several other advantages compared with conducting similar real-world studies on the road. Firstly, in the driving simulator, a number of participants could drive exactly the same route while only one factor at a time was varied, thereby enabling a controlled experimental setting and excluding obscuring effects of other factors. In the study, we used several factors and combined them in ways that would not have been possible in the natural setting in the field. In field conditions, uncontrolled factors such as changes in wildlife populations or movement patterns, weather conditions, traffic volume, driving conditions and time of the year could significantly affect the results. Secondly, the use of a simulator study reduced the risk of injury to drivers and animals. Measurement data from the simulator (speed in km/h) constituted the source material for the study.

2.1. Participants

A total of 25 participants (10 men and 15 women) were recruited for the simulator study. The official recruitment form issued by the Swedish Road and Transport Research Institute (VTI) was used to recruit these participants. This form asks people to provide data such as age, driving experience, nausea risk and contact details. Participants were contacted by phone for an appointment to