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Size speed bias or size arrival effect—How judgments of vehicles' approach speed and time to arrival are influenced by the vehicles' size

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ABSTRACT

Crashes at railway level crossings are a key problem for railway operations. It has been suggested that a potential explanation for such crashes might lie in a so-called size speed bias, which describes the phenomenon that observers underestimate the speed of larger objects, such as aircraft or trains. While there is some evidence that this size speed bias indeed exists, it is somewhat at odds with another well researched phenomenon, the size arrival effect. When asked to judge the time it takes an approaching object to arrive at a predefined position (time to arrival, TTA), observers tend to provide lower estimates for larger objects. In that case, road users' crossing decisions when confronted with larger vehicles should be rather conservative, which has been confirmed in multiple studies on gap acceptance. The aim of the experiment reported in this paper was to clarify the relationship between size speed bias and size arrival effect. Employing a relative judgment task, both speed and TTA estimates were assessed for virtual depictions of a train and a truck, using a car as a reference to compare against. The results confirmed the size speed bias for the speed judgments, with both train and truck being perceived as travelling slower than the car. A comparable bias was also present in the TTA estimates for the truck. In contrast, no size arrival effect could be found for the train or the truck, neither in the speed nor the TTA judgments. This finding is inconsistent with the fact that crossing behaviour when confronted with larger vehicles appears to be consistently more conservative. This discrepancy might be interpreted as an indication that factors other than perceived speed or TTA play an important role for the differences in gap acceptance between different types of vehicles.

1. Introduction

Crashes at railway level crossings are a problem that is usually not among the most prominent issues in discussions of road safety. Given that the number of fatalities at such crossings is relatively small compared to the total number of fatalities among road users, this is probably not surprising. However, from a railway perspective, such crashes are a much bigger deal. From 2010–2012, about 29% of fatalities from railway accidents (excluding suicides) occurred at level crossings in Europe (European Railway Agency, 2014). From 2002–2014, 117 level crossing users died in the UK alone, which prides itself as being "ranked first for safety performance in terms of level crossing accidents in Europe" (Office of Rail and Road, 2015). The numbers are similar in other parts of the world. In Australia, crashes at level crossings account for about 30% of rail related fatalities (Independent Transport Safety Regulator, 2011). From India, it is reported that crashes at level crossings regularly contribute about 50% of all rail accidents (Dubbudu, 2015). As the European Railway Agency (2014) states, "level-crossing safety might [. . .] be perceived as a marginal problem by the road sector, while it is a key problem for the railway" (p. 17).

In an attempt to explain the cause of crashes at level crossings, it has been argued that they might be the result of an apparent underestimation of an approaching train's speed. This hypothesis has first been put forward by Leibowitz (1985), who noted that larger objects appear to be moving more slowly than smaller ones. He used the example of observing aircraft at an airport, where larger aircraft would be perceived as travelling slower than smaller planes, despite having approximately the same velocities. Leibowitz' assumption has been often cited (e.g., Caird et al., 2002), but hardly ever been put to the test. Only recently have Clark et al. (2013) reported results from an experimental study backing up this hypothesis. In their setup, participants observed short video clips of virtual vehicles approaching from a point of view that could be considered comparable to the position of a vehicle waiting to cross. According to their results, a train would have to travel between

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85 km/h and 93 km/h to be perceived as travelling at the same velocity as a car at 80 km/h. Recently, they have followed this up with an eye-tracking study, in which they showed that this underestimation might be caused by the observers' visual focus on a position closer to the centre of the train, rather than the front (Clark et al., 2016).

While these results on observers' speed judgments are very clear and convincing, they nevertheless appear to be somewhat at odds with findings on road users' perception of the time it takes an object to arrive at a certain position ("time to arrival", TTA).[1] For the judgment of this TTA, research has usually found an effect quite the opposite of what Leibowitz suggested – namely, that larger objects are judged as arriving earlier than smaller ones, which should result in safer, not riskier crossing decisions. This so called size arrival effect was initially described by DeLucia (1991) for simple geometric shapes without any relation to the traffic context. In a series of experiments, she found evidence for this effect under a variety of conditions, including circumstances under which a more accurate judgment of TTA based on motion information should have been achievable with relative ease. Based on these findings, she suggested that the size arrival effect might play a role in road traffic crashes especially with smaller oncoming vehicles (DeLucia, 2013). Caird and Hancock (1994) investigated participants' TTA judgments of various approaching vehicles in a driving simulator, with participants seated in a full size vehicle, watching simulated motorcycles, cars and vans approach and providing an absolute judgment of the respective vehicle's arrival after it disappeared. Their results showed that the larger the vehicle, the smaller the estimated TTA, which lead the authors to state that the findings support "the margins-of-safety hypothesis that larger vehicles are given more space-time" (p. 97). Horswill et al. (2005) found similar effects when showing participants video material of real life motorcycles and cars approaching. The authors went so far to argue that this difference might account, at least partially, for crashes in which another motorist violates the right of way of a motorcyclist.

Indeed, this effect of vehicle size has also been observed for road users' actual behaviour. In one of the first studies to address the effect of vehicle type on drivers' gap acceptance, Bottom and Ashworth (1978) used an observational approach to find that motorists tended to accept shorter gaps when confronted with private cars, as compared to what the authors summarised as commercial vehicles. Keskinen et al. (1998) observed significantly shorter time gaps for motorcycles compared to cars. From a driving simulator study, Alexander et al. (2002) reported significant differences in accepted gap size between cars and trucks, again with the smaller vehicles eliciting smaller accepted gaps. Another driving simulator study found similar results for the comparison between vehicles of various sizes, albeit only descriptively (Hancock et al., 1991).

Given all this evidence pointing towards safer behaviour around larger vehicles, the experiment of Clark et al. (2013) warrants a closer look. One aspect of their study that clearly differs from others is the focus on speed instead of TTA. This is in line with Leibowitz (1985), who also mostly speculated on the perception of speed, not the time remaining until the train arrives at the crossing (although it should be mentioned that in his remarks, he also referred to the train's "expansion pattern", a variable which is usually considered to be the basis of TTA judgments). Another distinction is the specific focus on the train as the approaching vehicle. While studies on TTA have investigated vehicles of different size, a train has, so far, not been among these vehicles. Finally, there is a potential methodological issue that needs to be mentioned. In each single experimental trial, Clark et al. (2013) had their participants indicate which of two presented vehicles – an approaching train that varied in speed from trial to trial, and a car of constant speed – was faster. Unfortunately, the way that the different speed levels of the train and the reference speed level of car were set meant that there were more trials in which the train was the faster of the two vehicles than the other way around. A potential "good" participant expecting an even distribution and providing answers matching this assumption might create exactly the pattern of results that was observed.

The aim of the experiment reported in this paper was to address the apparent contradiction between size speed and size arrival effects by extending the experimental design of Clark et al. (2013). To achieve that, the experiment required participants to judge velocity and TTA on the same material, added a truck to the set of vehicles studied (as an example for a larger vehicle for which the size arrival effect had been observed previously), and changed the reference speed of the car to eliminate the potential methodological flaw.

2. Method

2.1. Participants

Thirty-nine students (33 female, 6 male) from Technische Universität Chemnitz with a mean age of 23.2 years (SD = 6.0) took part in the experiment. All but one were in possession of a driving license. All participants had normal or corrected-to-normal vision. They received course credits for their participation.

2.2. Material

Short video sequences of a simulated vehicle approaching the observer on a passing trajectory at a constant speed were created using 3DS Max 2014 (1680 × 1050 px, 25 fps). All video sequences were 1 s in length. While such a duration might appear to be rather short, it has been shown that an extension of viewing time beyond 1 s does not increase the accuracy of absolute time to arrival judgments (Sidaway et al., 1996). The authors concluded that TTA "can be estimated accurately with very limited presentations of optic flow." (p. 106).

The observer's position was that of a road user about to cross the approaching vehicle's trajectory. Three different vehicles were used: a truck, a train, and a car (see Fig. 1). All vehicles were coloured white, so that they could be easily distinguished from the background of the scenery. The overall setup, including camera position and environment, closely resembled the material of Clark et al. (2013). However, to account for the fact that Germany (the origin of this study) drives on the right side of the road, while New Zealand (the origin of the replicated study) drives on the left, the videos showed an approach from the left, instead of an approach from the right (as used in Clark et al., 2013).

The experiment consisted of two different blocks – a block in which participants were required to judge the speed of the approaching vehicles (speed block), and a block in which their task was to assess their time to arrival (TTA block). For that, a so-called relative judgment task (Tresilian, 1995) was used, in which observers have to judge which of two approaching stimuli would arrive first. For this experiment, this meant that a single trial always consisted of two video sequences, one of which showed either the truck or train, and the other one always showing the car as a reference. Participants were supposed to indicate which of

[1] In the literature, you also find the terms time to collision, time to contact, time to passage or arrival time, which all, more or less, describe the same concept. For reasons of consistency, the term time to arrival (or TTA) is used throughout this paper, as it best fits the experimental setup, and as it is broad enough to cover all the other terms. However, it has to be acknowledged that cited authors might have used different terminology.