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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.

Keywords: time to collision, TTA, gap acceptance, railways, trucks, crashes

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 to 2012, about 29% of fatalities from railway accidents (excluding suicides) occurred at level crossings in Europe (European Railway Agency, 2014). From 2002 to 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, 2002), but hardly ever been put to the test. Only recently have Clark, Perrone and Isler (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 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

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caused by the observers' visual focus on a position closer to the centre of the train, rather than the front (Clark, Perrone, Isler, & Charlton, 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, Helman, Ardiles and Wann (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

[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.

(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, Ota and Katila (1998) observed significantly shorter time gaps for motorcycles compared to cars. From a driving simulator study, Alexander, Barham and Black (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, Caird, & Shekhar, 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 (1680x1050 px, 25 fps). All video sequences were 1s in length. While such a duration might appear to be rather short, it has been shown that an extension of viewing time beyond 1s does not increase the accuracy of absolute time to arrival judgments (Sidaway, Fairweather, Sekiya, & Mcnitt-Gray, 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 Figure 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).

Figure 1. Screenshots of truck, train and car used in the experiment.

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 the two presented vehicles was travelling faster (speed block) or would have arrived earlier (TTA block). Participants provided their response by pressing one of two designated buttons. The experiment was implemented using OpenSesame (Mathôt, Schreij, & Theeuwes, 2012).

For the speed block, selected vehicle speeds and distances were the same as in Clark et al. (2013). We used their “intermediate” and “near” starting points for the vehicles (since, according to the authors’ account, there was no significant size speed illusion for their “far” condition, this condition was not implemented in this experiment). In the “intermediate” condition, half of the video sequences started with the vehicles in a distance of 100 m from the observer (i.e., dependent on speed, their final position varied), and the other half ended with the vehicle in a distance of 75 m from the observer (i.e., dependent on speed, their starting position varied). This variation was introduced to prevent participants from using either the initial or final vehicle position as an indicator for the vehicles’ speed. The same was done for the “near” condition, where the videos either started with the vehicles in a distance of 60 m, or ended in a distance of 15 m from the observer. The speed of the truck and train varied across trials from 60 km/h to 120 km/h, with increments of 10 km/h. The car was always travelling at 90 km/h. Table 1 gives an overview of the different factor levels, which resulted in a total of 56 trials for this block (2 vehicles x 7 speed levels x 2 positions (x 2 versions per position)).

Table 1. Overview of the different factors and factor levels in the speed block (additional details in italics).

Vehicle	Speed	Vehicle position
Truck	60 km/h	intermediate
Train	70 km/h	*(100 m from observer at start of video, or*
(Car as reference, always 90 km/h)	80 km/h	*75 m from observer at end of video)*
	90 km/h	near
	100 km/h	*(60 m from observer at start of video, or*
	110 km/h	*15 m from observer at end of video)*
	120 km/h	

In the TTA block, the central variable was the vehicles' time to arrival until reaching the observer's position. The car always had a TTA of 1.8 s at the end of the video, whereas for the other two vehicles, time to arrival varied from 1.2 s to 2.4 s, in increments of 0.2 s. To prevent participants from just using the vehicles' final position as an indicator for their time to arrival, vehicle speed varied. In the "similar" condition, one of the vehicles approached at 80 km/h and the other at 90 km/h. In the "dissimilar" condition, the respective velocities were 70 km/h and 100 km/h (all factor levels in Table 2). Just as the speed block, the TTA block contained 56 trials overall (2 vehicles x 7 TTA levels x 2 speed levels (x 2 combinations per speed level)).

Table 2. Overview of the different factors and factor levels in the TTA block (additional details in italics).

Vehicle	TTA	Vehicle speeds
Truck	1.2 s	similar
Train	1.4 s	*(Car 80 km/h, other 90 km/h, or*
(Car as reference, TTA always 1.8 s)	1.6 s	*Car 90 km/h, other 80 km/h)*
	1.8 s	dissimilar
	2.0 s	*(Car 70 km/h, other 100 km/h, or*
	2.2 s	*Car 100 km/h, other 70 km/h)*
	2.4 s	

2.3. Procedure

Participants were seated in a darkened room, in a distance of about 50 cm from a 24” flat screen on which the experiment was presented. First, they became acquainted with the nature of the video sequences. They were presented with some example screenshots and one video sequence in order to familiarise them with the overall setting. Then, one of the two different blocks (speed block or TTA block) was explained, followed by three practice trials (which used speed / TTA pairings for the vehicles that did not occur during experimental trials), before actual performance was measured on the first block. The same procedure (explanation, practice trials, measurement) was followed for the second of the two blocks. After measurement, participants provided demographic information via a short questionnaire. The whole experiment was completed in about 20 min, with the order of blocks counter-balanced for participants.

2.4. Analysis

As a measure of each participants’ speed and TTA assessment, a point of subjective equality (PSE) was identified for each of the two vehicles and both experimental blocks. In the speed block, this PSE describes the speed at which the respective vehicle (truck or train) had to travel to be perceived as being as fast as the reference car at 90 km/h. Accordingly, in the TTA block, the PSE describes the TTA at which the respective vehicle (truck or train) was perceived as having the same TTA as the reference car with a TTA of 1.8 s. To calculate the PSE, participants’ response patterns were used to create individual regression models to predict the probability that a certain speed or TTA of the truck or train is perceived as being higher/longer or lower/shorter than the speed or TTA of the reference car. The speed or TTA at which this probability was 50% (the transition point of the logistic regression line) was defined as the participant’s PSE (see Clark et al., 2013).

3. Results

The datasets of two participants were excluded completely from further analysis, as they clearly did not follow instructions (e.g., always pressing the same key throughout the experiment). In addition, if a participant had an accuracy below chance level for one or both of the two vehicles in one of the experimental blocks (e.g., only 45% correct responses for the truck in the TTA block), the participant’s data was excluded from the analysis of this specific block. Analyses of PSEs with regard to potential order effects showed no significant effect of block arrangement (speed first or TTA first) for any of the tasks.

In Figure 2, the mean PSE in the speed block (overall, as well as separately for the two distance conditions) is displayed for both truck and train. As can be clearly seen, both truck and train had to travel much faster than the reference car (broken line in Figure 2) to be perceived as moving at the same speed, regardless of the distance of the vehicles. This impression is confirmed by the results of the statistical analysis, in which the mean PSE for each vehicle, in each distance (as well as overall) differed significantly from the 90 km/h reference value (see Table 3 for all t-values, df, p-values and effect sizes), with large effect sizes throughout (Cohen, 1988). At the same time, the differences between the truck and train appear to be rather unsystematic, with the higher mean PSE in the near distance condition higher for the truck, and slightly higher for the train in the intermediate distance condition. However, none of these differences proved significant.

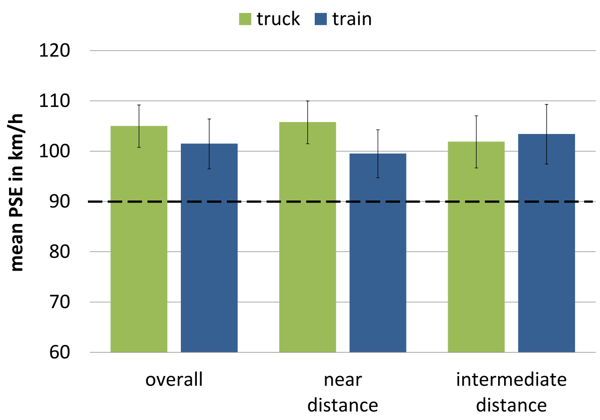

Figure 2. Mean PSE in the speed block for truck and train overall, as well as separately for the two different vehicle distance conditions. Broken line at 90 km/h indicates speed of the reference car. Error bars represent 95% confidence intervals.

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Table 3. Statistical analysis of the mean PSE in the speed block. One sample t-test against a value of 90 km/h in the truck vs. car and train vs. car comparison. Paired t-test in the truck vs. train comparison. Alpha-value adjusted to .017 to account for multiple comparisons (Bonferroni correction). Significant differences in boldface.

	truck vs. car			train vs. car			truck vs. train		
	overall	near	interm.	overall	near	interm.	overall	near	interm.
t-value (df)	7.26 (30)	7.56 (29)	4.67 (29)	4.72 (30)	4.06 (29)	4.62 (29)	1.34 (30)	1.96 (29)	-0.45 (29)
p-value	**< .001**	**< .001**	**< .001**	**< .001**	**< .001**	**< .001**	.190	.060	.656
effect size d	1.33	1.40	0.87	0.86	0.75	0.86	0.24	0.36	-0.08

Figure 3 shows the mean PSE for truck and train in the TTA block (overall, as well as separately for the two speed conditions). Unlike in the speed block, there appears to be a clearer difference between the truck and the train. For the truck, the mean TTA that was perceived as being equal to the car's TTA of 1.8 s (broken line in Figure 3) was much smaller than this reference value. In contrast, there was no such effect for the train, with the mean PSE rather close to the actual reference. This is confirmed by the statistical analysis (see Table 4 for all relevant statistics). For the truck, the tests showed significant differences compared to the reference overall, as well as separated into the two different vehicle speed levels, with medium size effects (Cohen, 1988). In contrast, no significant effect was found for the train. Despite this, the direct comparison of the mean points of subjective equality for truck and train did not uncover a significant difference between the two vehicles.

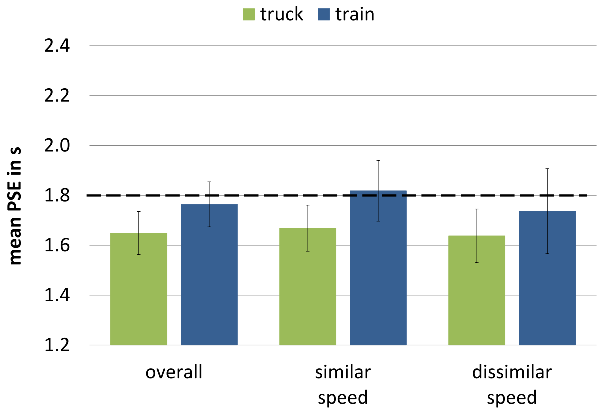

Figure 3. Mean PSE in the TTA block for truck and train overall, as well as separately for the two different vehicle speed levels. Broken line at 1.8 s indicates TTA of the reference car. Error bars represent 95% confidence intervals.

Table 4. Statistical analysis of the mean PSE in the TTA block. One sample t-test against a value of 1.8 s in the truck vs. car and train vs. car comparison. Paired t-test in the truck vs. train comparison. Alpha-value adjusted to .017 to account for multiple comparisons (Bonferroni correction). Significant differences in boldface.

	truck vs. car			train vs. car			truck vs. train		
	overall	similar	dissimilar	overall	similar	dissimilar	overall	similar	dissimilar
t-value (df)	-3.55 (35)	-2.88 (35)	-3.08 (31)	-0.81 (35)	0.31 (35)	-0.76 (31)	-2.20 (35)	-1.88 (35)	-1.17 (31)
p-value	**.001**	**.006**	**.004**	.422	.761	.453	.035	.068	.252
effect size d	-0.60	-0.49	-0.55	-0.14	0.05	-0.14	-0.37	-0.32	-0.21

4. Discussion

The aim of this experiment was to investigate how judgements of vehicle approach speed and time to arrival are influenced by the approaching vehicles' size. The results of the experiment are in line with the findings reported by Clark et al. (2013), who found a so-called size speed bias. An oncoming train had to travel much faster than a car for it to be perceived as approaching at the same speed. Moreover, the results were nearly identical for an oncoming truck, which also had to approach much faster in order to be perceived as travelling at the same speed as a car. However, against the background of the proposed explanation for this effect, the fact that there was no difference between train and truck has to be considered somewhat surprising. As Clark et al. (2016) found in their eye-tracking study, a train would be fixated farther from the front compared to a car, which they ascribed to the train's image being much longer. While the truck used in this experiment (Figure 1) was clearly longer than the car, it was also considerably shorter than the train, providing less opportunity to fixate farther from the front (in fact, in terms of length, the truck was much closer to the car than the train), which should result in a smaller effect compared to the train.

Results on the TTA judgments partially support the findings on speed judgments. The truck was perceived as arriving later than a car with the same TTA. There was no such effect for the train. However, the findings for both vehicles are in stark contrast to the size arrival effect, which would have suggested that truck and train would be judged as arriving earlier than the car. A potential explanation for the absence of this effect might be found in the observers' perspective. Especially in the classical studies on the size arrival effect, which employed rather artificial material (e.g., DeLucia, 1991), the object in question approached the observer head on, on what would be called an egocentric trajectory. A fixation farther from the front of the approaching object, as suggested by Clark et al. (2016), was practically impossible, as the observer had no view of the side of the object. It appears that if such a side view is available, the effect of the displaced fixation is able to override the size arrival effect. In that regard, the view used in this experiment might be considered the minimum angle required to allow for some side view of the approaching vehicle, which might be blamed for the finding that there was no clear difference between truck and train with regard to the speed estimates. In actual crossing decisions, which often would include a slow approach of the level crossing, drivers would start collecting information about the intersecting vehicle at a much more oblique angle. At this point however, it is difficult to speculate about potential explanations for the lack of a difference between truck and train speed estimates, as no eye-tracking data was collected to assess where exactly the participants were looking when judging the speed of train, truck and car in this experiment.

While it might be possible to explain the absence of the well-known size arrival effect on TTA judgments in this experiment, the fact that crossing behaviour when confronted with larger vehicles appears to be consistently more conservative (Alexander et al., 2002; Bottom & Ashworth, 1978;

Hancock et al., 1991; Keskinen et al., 1998) remains. This discrepancy might be seen as an indication that perceived speed or TTA actually play only a minor role for the differences in gap acceptance between different types of vehicles. Instead, other aspects like the "expected cost of an accident", which "may depend on whether the oncoming vehicle is a rickshaw or a bus" (Das, Manski, & Manuszak, 2005; p. 545) have to be considered as potential factors in road users crossing decisions. If such considerations indeed influenced driver gap acceptance, it would have to be assumed that when faced with an oncoming train, road user's decisions would be extremely conservative.

This highlights a central methodological issue. The use of the results on speed and TTA judgments as an explanation for an individual category of crashes, in this case crashes on level crossings, is highly problematic. Even if this crash type is a key problem for railway operations, it is an extremely rare occurrence. Drivers manage to cross railway tracks without crashing every day, even though the data indicates that they might underestimate an approaching train's speed considerably. At the same time, even if decisions were extremely conservative, there would be some crashes. Either way, for a crash to occur, something unusual would have to happen. So, while underestimations of speed (or overestimations of TTA) might be suspected to be contributing factors, it is fair to assume that other aspects, such as the driver's age and gender, driver traits and driver states, are just as responsible for the poor crossing decisions that ultimately lead to crashes on level crossings. For example, younger drivers (e.g., Leung & Starmer, 2005), male drivers (e.g., Yan, Radwan, & Guo, 2007) as well as drivers with a high level of extraversion (Bottom & Ashworth, 1978) or a high desire for control (Hammond & Horswill, 2001) have a tendency to take riskier gaps to cross or overtake. Driver intoxication with alcohol or certain types of drugs (e.g., Brookhuis, Waard, & Samyn, 2004; Simons et al., 2012) also leads to reductions in accepted gap size, while when distracted, drivers appear to neglect relevant environmental cues (such as road surface conditions) in their decision (Cooper & Zheng, 2002). Given the number of potentially contributing factors, the role that faulty estimations of speed or TTA might play in such crashes should not be overestimated.

In addition, while the results especially on the speed judgments imply that the risk of colliding with a train would have to be higher compared to collisions with other vehicles (everything else being equal), it is unclear if that is actually the case. There is hardly a suitable way to compare the number of crashes involving trains with the number of crashes between other motorised road users (ideally on comparable types of crossings, such as depicted in the experiment, controlled for exposure, etc.). But only if such a comparison could show an increased risk for level crossing crashes with trains, the differences in speed estimation between cars and trains would be valuable in providing an explanation for such an increased crash risk. If there is no increase in risk, it is likely that the differences in estimated mean speed cannot serve to explain crashes on level crossings.

It is therefore vital to extend the research on speed and TTA judgments of oncoming trains to include actual crossing decisions, and, ultimately, crash data. Given that the dimensions of a railway track (particularly the width) are quite different to a single carriage x or t-intersection, experimental and observational studies that address gap acceptance behaviour especially when confronted with an approaching train are required to help understand the relationship between judgment and action in this specific scenario. A first step into this direction might be to redesign the experiment reported in this paper to be able to study crossing decisions using the same material. As has been shown before, by using identical material to test TTA judgments and crossing decisions, potential biases in gap acceptance can be linked to similar biases in the judgment of TTA (Petzoldt, 2014). Such an approach might help clarify in how far the size speed bias directly translates into differences in gap acceptance.

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