Examining the Effectiveness of Musical Roads' Auditory Cues in Encouraging Adherence to Road Speed Limits

Arina Fayzulina
Student number: 2803544
a.fayzulina@student.vu.nl

Judith Mashudi
Student number: 2818805
j.l.mashudi@student.vu.nl

Tharani Shanmugam
Student number: 2821746
t.shanmugam@student.vu.nl

Thanh Thanh Nguyen
Student number: 2821286
t.t.r.nguyen@student.vu.nl

Keira Zieboll
Student number: 2680132
k.s.zieboll@student.vu.nl

Abstract

Road traffic injuries remain a global concern, with leading causes like speed decisions and driver inattentiveness. Rumble strips, a common road safety measure, are shown to have positive effects on driving behaviour by influencing speed choices and attention. Building upon this concept, musical roads were developed, utilising rumble strips to generate musical notes as vehicles pass over them, offering an additional auditory experience with the potential to encourage appropriate driving speeds. This study investigates the impact of musical roads on drivers' speed adjustment decisions and ability to accurately determine the correct speed using an OpenSesame-based experiment. Participants were instructed to adjust the speed of 11 musical road audios to determine the correct driving speed. The results indicated that participants did not always accurately determine the correct speed. Additionally, individuals recognized when the given audio was too slow, leading to increased speed adjustments. However, when the provided audio was at the correct speed or faster, significant speed changes were less prominent. This suggests that the novelty and musical tempo of musical roads can influence driving speed, but not always in the intended safety-enhancing direction. Accordingly, while musical roads offer an innovative approach to influencing driver behaviour, its actual efficacy in promoting safer driving speeds remains nuanced.

I. Introduction

Millions of human lives are impacted by road traffic injuries every year (World Health Organization [WHO], 2022). One of the difficulties drivers face on the road is the choice of speed due to the periodic presence of speed signs and a lack of alignment between the physical appearance of a road and its enforced speed limit. Additionally, as drivers tend to drive on “autopilot” in familiar environments or have their attention fixated elsewhere, traffic signs are often missed (Charlton et al., 2018). Hence, the innovative construction of road infrastructures that intuitively engage with drivers to encourage safe driving practices plays a crucial role in road safety. Among conventional safety measures are rumble strips, which are designed to have a direct influence on two of the most prominent causes of road traffic injuries: speeding and distracted driving (Persaud et al., 2004; WHO, 2022). Positioned perpendicular to the direction of transport, rumble strips are elevated or grooved designs that produce audible and tactile sounds when a vehicle's tire passes over them (Persaud et al., 2004).

In recent years, the innovative idea of musical roads has emerged from the foundational concept of rumble strips. Musical roads utilise rumble strips to generate specific musical sounds or melodies through micro-vibrations that occur when a vehicle drives over them. The music produced is perceivable both on the inside and outside of the means of transport (Zhou et al., 2018). Such musical roads not only contribute to creating unique auditory experiences for drivers, but the use of rumble strips also implies a potential method for encouraging safe driving behaviour related to speed and attention. This is based on the assumption that drivers will maintain the proper speed in order to hear the song at an accurate speed.

Musical roads have been around since the 90’s. However, there are little to no studies about their effects on people’s driving speed or behaviour. As mentioned earlier, rumble strips are, on the contrary, common road safety features. Studies have shown that they support safer driving behaviour (Horswill & Plooy, 2008; Kermit & Hein, 1962). One study on the effect of rumble strips on driving behaviour shows that with the installation of rumble strips, a 30% reduction in vehicle speed is realised (Horswill & Plooy, 2008). The reduction in speed is an indicator of the impact of rumble strips on driving behaviour. Another study by Kermit & Heim (1962) shows that when placing rumble strips before stop signs, the percentage of people doing a full stop increased from 47% to 74%, causing people to comply more with the sign. This result not only promotes traffic law adherence but also underscores the capacity of road features to influence driver behaviour positively. It also reduced centerline violations from 26% to 15%, in addition to promoting safer deceleration and speed compliance. This signifies that rumble strips are likely to promote safer deceleration and speed compliance, thus enhancing overall road safety. Collectively, these findings indicate that the tactical and audio elements of rumble strips capture drivers’ attention, causing them to change their behaviour. Additionally, a study on the effect of auditory feedback on driving behaviour finds that reduced noise in the car makes participants more likely to underestimate their speed. Consequently, they might be more likely to increase their driving speed (Horswill & Plooy, 2008). This implies that auditory feedback plays a role in drivers' ability to estimate speed.

This study sought to investigate the impact of driving on musical roads with predefined initial speeds on individuals' speed adjustment decisions, and examine whether participants could accurately determine the correct driving speed while listening to audio from musical roads. In the realm of cognitive psychology, our study investigates how individuals perceive and interpret sensory information, emphasising the relationship between **sensation** and **perception**. We explore how drivers respond to auditory cues from musical roads, which serve as external stimuli in their driving environment, capturing their **exogenous attention** and influencing driving behaviour. Our investigation also assesses whether the **challenge of ambiguity** is present when sensory information allows for different interpretations.

The experiment was conducted in OpenSesame involving a group of participants recruited from among family, friends, and acquaintances. In the experiment, participants were provided with 11 different musical roads and their corresponding musical sounds, which represented driving speed. The participants were tasked with adjusting the speed of the musical sound and thereby testing the ability of musical roads to promote accurate driving speeds. By examining how individuals respond to musical roads with specific initial speeds, this report aims to answer the following **research question**: *How does driving on a musical road with a specified initial speed influence a person's speed adjustment decisions, and can individuals accurately determine the correct speed while travelling on musical roads?*

The independent and dependent variables for this experiment are the initial speed of an audio and the participants' chosen speed (*answer*) respectively. Additionally, an aggregate variable that is used in our study as a dependent variable is the difference between answer and initial speed (*change*). The research question, alongside the independent and dependent variables, prompts the formulation of the following hypotheses:

H1. If the initial speed is increased (decreased), participants should decrease (increase) the speed, and keep it if the initial speed is correct.
H2. Participants can accurately determine the correct speed, regardless of the initial speed.

II. Methods

A. Participants

For the current study, a number of 21 participants were recruited through limited approaches. As it was not possible to publish the experiment online, individuals could only participate with the use of the personal electronic devices of the researchers. The research population, therefore, solely consisted of family, friends, and other acquaintances. All participants completely finished the online experiment and were not granted any additional reward.

B. Stimuli and equipment used

The experiment was both hosted and created using OpenSesame, a software tool for designing experiments (Mathôt, 2012). In total, the experiment consisted of 4 parts: 1. consent and introduction 2. demographics+control question 3. actual experiment 4. thank you screen. As the experiment was conducted using the researcher's personal devices, there was always someone accompanying the participant. This made sure that the surroundings of the participant were quiet and that they fully comprehended the task. In addition, the experiment could be taken both during the day and in the evening, as lighting was not an important factor. During the experiment, the participants were given 11 pictures of existing musical roads and the corresponding musical sound. The material of both pictures and sounds were retrieved from various youtube videos; for an overview of the material, please see the appendix (Section V). Photos were used instead of videos to prevent participants from modifying the video speed. Since real videos from YouTube were used, shooting instability and potential speed adjustments could inadvertently affect participants' responses by providing clues about the correct speed to choose. The task of the participants was to focus on the musical sound and make real-time driving decisions based on the sound. There was no time limit on the task, meaning that the participant would move on to the next trial once they had finished the current trial.

C. Design

As previously mentioned, each trial involves an image of the road paired with an audio track. The audio's playback speed is randomly set at its original speed, sped up, or slowed down, and stored in the *init_speed* variable. The speed increment is equal to 0.2, allowing *init_speed* to take one of three possible values: 1.0, 1.2, and 0.8, representing the original speed, sped up, and slowed down, respectively. Participants must select the perceived correct speed within a predefined speed limit (initial audio speed ± 0.4), following the sliding window principle, which offers participants a choice of five different speeds. In other words, participants can increase the audio speed by 0.2 twice or decrease it by 0.2 twice starting from the initial speed. These conditions create three distinct speed interval scenarios based on the randomly chosen initial speed, as illustrated in Figure 1. The chosen speed is recorded as the *answer* variable, which can assume one of seven possible values ranging from 0.4 to 1.6 with an increment of 0.2.

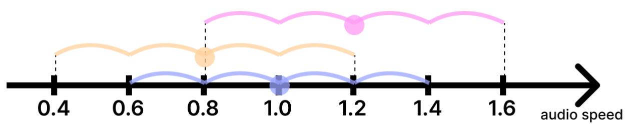

Figure 1. Sliding window: 3 speed interval scenarios based on random initial speed choice

Additionally, the *change* variable was computed, representing the difference between the chosen speed and the initial speed. This variable provides us with a numerical representation of how much participants alter the initial audio speed. The *change* variable assumes a positive value if the speed was increased relative to the initial speed and a negative value if it was decreased. Given the details described above, the *change* variable can take one of five different values, ranging from -0.4 to 0.4, in increments of 0.2. The summary of variables used in the experiment is provided in Table 1.

Table 1. Independent and dependent variables

	Variable	Description	Possible values
Independent variable	*init_speed*	initial speed of an audio given to the participant	0.8, 1.0, 1.2
Dependent variable	*answer*	speed chosen by the participant	0.4, 0.6, 0.8, 1.0, 1.2, 1.4, 1.6
	change	answer - initial speed => positive if speed increased, negative if speed decreased	-0.4, -0.2, 0, 0.2, 0.4

D. Procedure

Before participating, the participants were informed that they were going to participate in an online experiment for a master project that involved a task. Initially, they were asked for their consent and received some background information on the experiment. The next part of the experiment consisted of demographic questions and an additional control question. The participants were asked their age, gender, and whether they have any driving experience. After this the experiment was further introduced and explained. Specifically, they were told that “ we are interested in whether the presence of musical rumble strips on the road lead to better driving speed accuracy". After the introduction, the participants would begin the actual experiment involving 11 similar trials that were given in random order. Their task was to get to the correct driving speed based on the musical sound that they heard, meaning that they are driving the correct speed when they hear the correct speed of the musical sound. They could alter the speed by using different key presses. The upwards facing arrow key would increase the speed with .2 and the downwards facing arrow key, would decrease the speed with .2. Once they are satisfied with their answer, they could lock their speed using the space bar, which would then bring them to the next trial. After completing the task for the 11 different musical roads, a thank you screen was shown after which the experiment would end.

III. Results

To assess how participants adjusted their speed in relation to the initial speed they were driving with, a linear mixed-effects model (LMM) was used with the change in speed (*change*) as the dependent variable. The model includes initial speed (*init_speed*) as a fixed effect and random intercepts for subjects (*subject*) and road numbers (*road_nr*), along with random slopes. The intercept is removed from the model since our focus lies in the effects of initial speed on speed change for every level of initial speed, rather than these effects relative to a specific reference level.

Model 1: *change ~ -1 + init_speed + (1 + init_speed | subject) + (1 + init_speed | road_nr)*

To investigate whether participants can accurately determine the correct speed regardless of the initial speed, a LMM analysis was conducted with the chosen speed (*answer*) as the dependent variable. The fixed and random effects in this model are the same as in the Model 1. However, in this case, the intercept was kept, which allows us to examine whether participants' choices change relative to the reference level (*init_speed* = 1.0).

Model 2: *answer ~ init_speed + (1 + init_speed | subject) + (1 + init_speed | road_nr)*

To analyse the results of both models, report coefficients' values, SEs and t-values are reported, and t-values beyond the interval [1.96; -1.96] are considered significant.

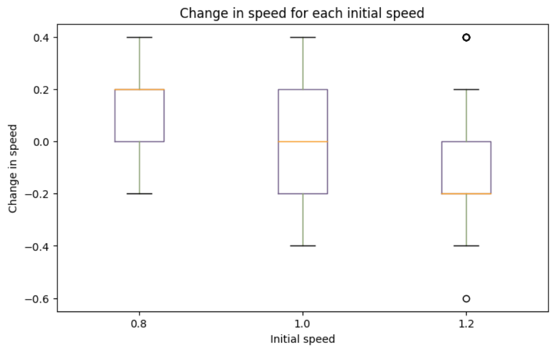

Figure 2. Change in speed for different levels of initial speeds

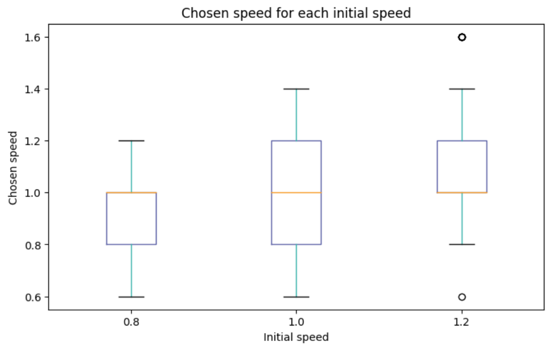

Figure. 3. Chosen speed across different initial speeds

The boxplot in Figure 2 appears to visually illustrate variations in speed changes for different initial speeds; however, analysis of the LMM model is needed to draw conclusive conclusions. Based on the results of Model 1, it is observed that, when the initial speed is decreased to 0.8, participants, on average, increase their chosen speed by approximately 0.13735 units relative to the initial speed. This finding is statistically significant, as indicated by a t-value of 3.375 (SE=0.0407), which exceeds the threshold of 1.96. This aligns with our prediction. However, the coefficients for initial speed levels 1.0 and 1.2 yield t-values of 0.492 and -1.704 (SE=0.0368 and SE=0.0446), respectively, so the coefficients for these levels of initial speed are not statistically significant. Therefore, our hypothesis which states that participants should decrease (increase) the speed if the initial speed is increased (decreased), and keep it if the initial speed is correct, is partly supported by the model results.

A bar chart (Figure 4) was generated to visualise the distribution of participant responses, providing additional insight into their choices. The results indicate that the majority (87) of responses were accurate, and less accurate answers were less frequent in comparison. Notably, the answer value of 0.4 was also an option, but it was never chosen by any participant. Additionally, examining the boxplot in Figure 3 reveals that participants' chosen speeds vary with the initial speed, aligning closely with 1.0 and making slight adjustments for higher or lower initial speeds. However, to conduct a thorough analysis of the answers, it is crucial to examine the results in Model 2.

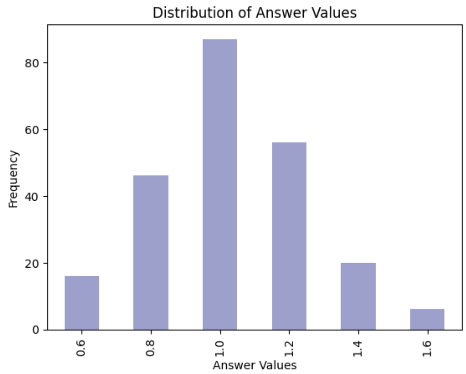

Figure 4. Frequency distribution of answer choices

In Model 2, statistical significance is confirmed for the intercept and two coefficient effects, decreased and increased initial speed, with t-values of 27.687, -2.776, and 3.504 (SE=0.0368, SE=0.0291, SE=0.0302), respectively. On average, when the initial speed is 1.0, participants choose a speed near 1.0, but at 0.8 or 1.2 initial speeds, they adjust their choices, slowing down (by 0.0807) and speeding up (by 0.1059) in relation to the reference speed of 1.0. Therefore, participants' choices are influenced by the initial speed, exhibiting positive correlation, and the hypothesis that participants can accurately determine the correct speed regardless of the initial speed is not supported by these results. See appendix (Section V) for more details about the model results.

IV. Discussion

The current study aimed to investigate the influence of musical roads on individuals' driving speed behaviour. The experiment's findings indicated that driving on a musical road with a specified initial speed significantly influences a person's speed adjustment decisions when the initial speed is decreased. However, the influence may not be significant for the original and increased initial speeds. Additionally, individuals may not always accurately determine the correct speed while travelling on musical roads, and their choices are influenced by the initial speed.

One important result from this experiment (relating to hypothesis 1) is that participants could quickly recognise when the given audio was too slow, and increase its speed accordingly. However when the audio was at the correct speed or too fast, they did not significantly change their speed. So, the experiment rejected our first hypothesis. From this it can be inferred that people are more likely to drive at the same speed or faster when a musical road is present. One explanation of this result could be that musical roads provide drivers with a sense of novelty, due to their rareness. Seeing (unexpected) signs signalling a musical road increases exogenous attention by bringing more focus to the road environment (Underwood et al., 2003). Subsequently, anticipation of this new experience of driving along a musical road increases endogenous attention, as drivers become invested in the experience based on prior (likely positive) memories and experiences of listening to music, which will excite drivers' neurons at the level of perception (Schäfer & Fachner, 2015). As a result, drivers are more eager to search for cues to determine the correct speed of the song. Especially when the initial audio speed is slower, this could increase their motivation to drive faster, as they aim to hear more notes.

However, it is important to note that this finding could also be explained by participants' unfamiliarity with the songs played. The vast majority of musical roads are located in areas outside of Europe and the USA, and this was reflected in the musical roads in our study. Furthermore, many musical roads use songs that hold significance to the respective region or country. Therefore, it is likely that participants did not know the correct speed of the songs, and this increased their eagerness to search for cues instead. Familiarity with the songs could potentially enhance the accuracy of selected speeds through the lens of **top-down processing**, as prior knowledge and experience significantly shape the way individuals perceive and interpret sensory information.

A second important result from our study (relating to hypothesis 2) was that when the initial audio speed was too slow, participants decreased the audio speed more, and when the initial audio speed was too fast, they increased the speed more. These results indicate that the experiment rejected our second hypothesis. One explanation for this result is that songs with a faster tempo cause an increased physiological response (eg. faster heart rate) (Wen et al., 2019), so drivers are likely to feel more excited and are more likely to drive faster. On the other hand, songs with a slower tempo are perceived as more calming, as the slower beat reduces physiological responses (Wen et al., 2019). Drivers may want to maintain this state of calm, so are more likely to drive slower. This shows that the choice of music tempo for the musical roads is a key factor in their success as speed limit controls, and practitioners should use slower songs if they wish to encourage drivers to reduce their speed.

As before, this result could also be influenced by participants' familiarity with the songs. However, even if it is assumed that participants were familiar with every song, this might not explain all of the observed behaviour. For instance, if participants do know the correct audio speed, they may be more likely to drive at a different speed than the correct one, in order to manipulate the speed of the sound for fun. This links to the **prospect theory** of decision making, as drivers predict that they will gain more happiness from the novelty of being able to manipulate their environment (McDermott, Fowler & Smirnov, 2008) in order to hear a familiar song play at the wrong speed.

Overall, within the field of cognitive psychology, the results from hypothesis 1 indicate that, when faced with decreased initial speeds, sensory cues significantly influence individuals' driving adjustments, demonstrating the dynamic interaction between **sensation** and **perception**. This phenomenon illustrates the concepts of **exogenous attention**, where external auditory stimuli capture drivers' focus, and **endogenous attention**, where prior experiences affect their perception of the stimuli and influence their choices. Additionally, our findings from hypothesis 2 highlight the **challenge of ambiguity** in perception when sensory information allows for multiple interpretations. This observation underscores the idea that individuals may interpret ambiguous sensory information in varying ways when driving on musical roads depending on their individual physiological differences and prior experiences.

As for the limitations of the current study, one aspect that could be improved is the addition of the initial speed (*init_speed*) variable as a factor, rather than randomly generating it during the trials. This would enable a within-subjects design to be used, which would test every possible initial speed for every possible musical road item for each participant. As a result, this would ensure certainty that the observed effects are due to the differences in initial speed, rather than the features specific to the individual musical roads themselves.

Another theoretically interesting avenue for further study could be a comparative study of the effectiveness of musical roads and regular rumble strips on speed reduction. This is because the addition of a musical stimulus may increase attention on the road in comparison to regular rumble strips, due to the addition of auditory stimulation which stimulates neuron input. This could likely lead to differences in chosen speed. On the other hand, Zhou et al. (2018) show that musical roads are 20-30% more expensive to build than regular roads. Therefore, it may be assumed that musical roads require extra monetary and temporal resources to build in comparison to regular rumble strips, as a result of the necessary extra calculation of the correct spacing of grooves. The results of this study would therefore make both a useful contribution to the academic literature on road design, as well as road design and construction professionals, in determining whether the extra effort involved in adding music to rumble strips causes a significant impact.

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V. Appendix

Table 2. Stimuli used in the experiment

	Name of the road and location	Song	Correct speed (km/h)	Actual speed (km/h)	Link
1	R67, Mernye, Hungary	Republic - A 67-es Út https://www.youtube.com/watch?v=HE4aAQCghGs	80	80	https://www.youtube.com/watch?v=7-4psc5Yhxc
2	R37, Szerencs, Hungary	Delta - Érik a szőlő https://www.youtube.com/watch?v=tKHHnjrpPrM	80	80	https://www.youtube.com/watch?v=MkSCUL_j5v4
3	R66, Albuquerque, Tijeras, New Mexico	America the beautiful https://www.youtube.com/watch?v=7b_p4ppxr8s	72 (45 mph)	72	https://www.youtube.com/watch?v=o1Jm1zimCH0
4	Lancaster, CA	William Tell Overture https://www.youtube.com/watch?v=c7O91GDWGPU	88 (55 mph)	88 (55 mph)	https://www.youtube.com/watch?v=EK1ocEbJA7c
5	Anyang, South Korea	Mary Had A Little Lamb https://www.youtube.com/watch?v=CkRdvGmcCBE	100	100	https://www.youtube.com/watch?v=NsDZhxTy_xw
6	Kangwonland, South Korea	Mountain wind, river wind https://www.youtube.com/watch?v=yvwHKqtojI0	80	80	https://www.youtube.com/watch?v=STSY-SCqkBo
7	Ordos City in Inner Mongolia, China	Ode to the Motherland https://www.youtube.com/watch?v=Wnu-tBiXXJI	45 (28 mph)	45 (28 mph)	https://www.dailymotion.com/video/x7tw0v8
8	Netherlands (Jelsum)	Frisian national anthem https://youtu.be/CfiX416jTGg?t=37	64 (40 mph)	64 (40 mph)	https://youtu.be/Sw7w96qrGdA
9	Tsumagoi Village, Japan	Snowy Mountain Song of Praise	40	40	https://youtu.be/WbUCgoN93DM?t=459
10	Shima Onsen, Gunma, Japan	Always With Me (from the feature animation Spirited Away) https://www.youtube.com/watch?v=tBSthP5LTZU	40	40	https://www.youtube.com/watch?v=UsbXRzgsLkg
11					https://www.youtube.com/watch?v=bPraOQ00msY

```
Linear mixed model fit by REML ['lmerMod']
Formula: change ~ -1 + init_speed + (1 + init_speed | subject) + (1 +
init_speed | road_nr)
   Data: data

REML criterion at convergence: -117.4

Scaled residuals:
     Min       1Q   Median       3Q      Max
-2.66914 -0.59233  0.02242  0.62163  2.43038

Random effects:
 Groups   Name          Variance  Std.Dev. Corr
 subject  (Intercept)   9.122e-03 0.095509
          init_speed0.8 1.601e-03 0.040017 0.72
          init_speed1.2 3.732e-03 0.061092 0.40  0.92
 road_nr  (Intercept)   6.041e-03 0.077725
          init_speed0.8 7.134e-06 0.002671 -1.00
          init_speed1.2 2.977e-04 0.017253  1.00 -1.00
 Residual               2.529e-02 0.159036
Number of obs: 231, groups:  subject, 21; road_nr, 11

Fixed effects:
              Estimate Std. Error t value
init_speed1    0.01809    0.03677   0.492
init_speed0.8  0.13735    0.04069   3.375
init_speed1.2 -0.07600    0.04460  -1.704

Correlation of Fixed Effects:
            int_s1 in_0.8
init_spd0.8 0.723
init_spd1.2 0.740  0.780
optimizer (nloptwrap) convergence code: 0 (OK)
boundary (singular) fit: see help('isSingular')
```

Figure 5. results for Model 1

```
Linear mixed model fit by REML ['lmerMod']
Formula: answer ~ init_speed + (1 + init_speed | subject) + (1 +
init_speed |      road_nr)
   Data: data

REML criterion at convergence: -117.4

Scaled residuals:
     Min       1Q   Median       3Q      Max
-2.66916 -0.59235  0.02242  0.62158  2.43037

Random effects:
 Groups   Name          Variance  Std.Dev. Corr
 subject  (Intercept)   9.120e-03 0.095499
          init_speed0.8 1.602e-03 0.040025 0.72
          init_speed1.2 3.733e-03 0.061100 0.40  0.92
 road_nr  (Intercept)   6.040e-03 0.077717
          init_speed0.8 7.071e-06 0.002659 -1.00
          init_speed1.2 2.976e-04 0.017252  1.00 -1.00
 Residual               2.529e-02 0.159036
Number of obs: 231, groups:  subject, 21; road_nr, 11

Fixed effects:
              Estimate Std. Error t value
(Intercept)    1.01809    0.03677  27.687
init_speed0.8 -0.08074    0.02908  -2.776
init_speed1.2  0.10590    0.03022   3.504

Correlation of Fixed Effects:
            (Intr) in_0.8
init_spd0.8 -0.253
init_spd1.2 -0.124  0.537
optimizer (nloptwrap) convergence code: 0 (OK)
boundary (singular) fit: see help('isSingular')
```

Figure 6. results for Model 2