THE CONTRIBUTION OF MUSIC IN DRIVERS' TIME-TO-ARRIVAL ESTIMATIONS

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THESIS ABSTRACT

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Driver accuracy in decision-making and estimation is essential to the safety of everyone on the road. Numerous studies have highlighted the failings of drivers' abilities in critical areas and demonstrated drivers' tendencies to severely underestimate speed, susceptibility to overestimate time-to-arrival, and reliance on perceptions of time which are influenced by stimuli such as music or conversation (Schutz et al., 2015; Horswill et al., 2005; Brodsky & Slor, 2013). The purpose of the present study was to measure how music affected judgments of speed. To test this, observers were shown a series of videos in which their visual processing was interrupted and were asked to estimate when an approaching test car would have arrived. The results of the study indicated that tempo did not have an effect on time-to-arrival estimations, but that speed did affect time-to-arrival estimations. These results suggest that drivers' musical choices may not be as important as previously thought for their abilities to make accurate estimations of the amount of time they have before an oncoming vehicle will reach them.

The contribution of music in drivers' time-to-arrival estimations

Introduction

With estimates of the number of registered vehicles in the world nearing 2 billion and rising, increasing the safety of vehicular travel has only become more important (World Health Organization, 2015). While there are a multitude of potential avenues to achieving this goal, one direct and immediate impact could be found in an intervention which helps to reduce drivers' perceptual errors. Prior research has indicated that drivers make a consistent pattern of errors. Notably, drivers have a tendency to robustly underestimate speed by an average of 24% for both their own vehicle and other vehicles on the road (Schutz et al., 2015). In addition, headlight arrangement and ambient lighting conditions influence speed perception, with subjects underestimating oncoming motorcycle speed by an average of 56 miles per hour at night (Gould et al., 2012).

People also tend to make other, non-vehicular specific errors which may contribute to errors while driving. Small-scale digital time-to-arrival is typically overestimated, meaning that the target stimulus reached a designated location *before* viewers estimated that it had, by an average of half a second (Landwehr et al., 2013). Half a second may not seem like a meaningful error in time, but at 60 miles per hour, a half a second is a distance error of 44 feet. Perception of time passage is also influenced by external stimuli, such as the presence or absence of music (Droit-Volet et al., 2010).

All of these tendencies may have an impact in time-to-arrival estimations. Time-to-arrival (TTA) is, in the context of traffic psychology, the time between when a car is noticed by a driver and the time when that car has reached the driver. Similarly to speed estimation, time-to-arrival estimation provides essential information to drivers and is used to decide whether there is enough time and space to pull out in front of an oncoming vehicle. The consequences of misjudging this interval can range from a crumpled fender to a fatal accident, and drivers tend to make this critical judgement quickly and frequently on the road. Even if the chance of a single error is small, over thousands of instances, the risk for eventually making an error becomes unacceptably large.

In determining which component (or set of components) contributes most to drivers' perceptual errors, it is important to consider the elements which comprise an estimation of TTA: distance, speed, and time. Each of these elements can be described using the other two, with the formula:

$$time = \frac{distance}{speed}$$

Previous literature as discussed below indicates that people are generally prone to errors in both perception of speed and perception of distance. However unlikely, it may be the case in TTA estimation that people make completely accurate estimations of both speed and distance, and so come up with a correct duration until an oncoming vehicle reaches them. If this is true, there is *still* a potential for errors in TTA estimation if people misperceive the passage of time, a tendency for perceptual error which is also evident in previous literature. It is therefore not unreasonable to suspect that drivers may be susceptible to errors in time perception caused by the tempo of the music playing in their cars, nor is it unreasonable to hypothesize that such an error could influence TTA estimation. The goal of the present study was to examine the potential for the tempo of a musical stimulus to affect TTA estimations by altering time perception.

Speed Estimation Errors

Humans remarkably underperform when estimating the speed of vehicles travelling faster than 30 miles per hour. When pedestrians were asked to estimate the speed of vehicles in a busy divided roadway, they *increasingly* underestimated speed. The average estimation of speed was 3.4 miles per hour slower than the actual speed of the vehicle, but in conditions where the target vehicle's actual speed was over 40 miles per hour, subjects' estimations were 9.3 miles per hour slower (Sun et al., 2015). Similar findings were reported by Schutz et al. (2015), who performed a field test with subjects as passengers and drivers on an open track. Drivers instructed to accelerate to and maintain a given speed exceeded that speed by 20% on average, while passengers gave underestimates of their speed by an average of 24%. This bias to underestimate speed was also present when subjects were asked to estimate the speed of an oncoming vehicle, with the average estimate being 24% slower than the actual speed of the vehicle.

Burnett et al. (2017) found that drivers decreased their speed as a result of a subliminal shift in the spatial positioning of music from the front to the rear of the car, suggesting that drivers' speed estimations are vulnerable to influence from musical stimuli. Brodsky (2002) found additional support for the impact of music on speed estimation and driving behavior, noting that drivers who listened to fast-tempo music in a simulator drove faster and estimated their speed to be faster. These findings indicate not only that speed is consistently misestimated, but that speed perception can be affected by external stimuli, such as music.

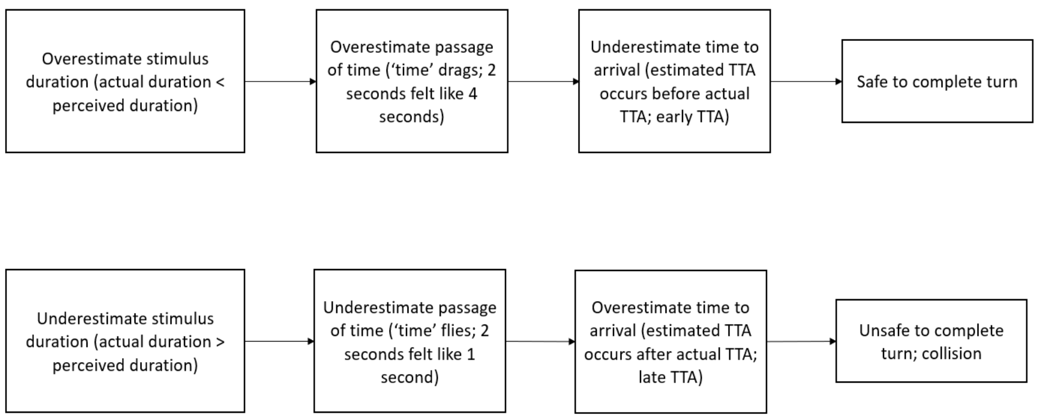
Distance Estimation

In keeping with their tendency for underestimating speed, subjects have also demonstrated susceptibility to errors in their judgements of distance, with a tendency to underestimate true distance by as much as 70% in a stationary-estimation paradigm (Saffarian et al., 2015). Drivers have been found to underestimate distance to a greater degree than pedestrians (Moeller et al., 2016). People are susceptible to size and distance constancy illusions such as the Ponzo illusion, where two lines of equal length appear to be different sizes based on their background, and the Moon illusion, where the moon appears much larger when it is near the horizon, so it is not unreasonable to imagine that similar perceptual errors can occur in time- and information-limited scenarios such as driving. Somewhat in contradiction to research discussed above, Santillán and Barraza (2019) found that people, while in motion, tended to overestimate the distance that a target traveled, which may arise from people compounding their own movement with that of other objects or people; the driver of a car at an intersection could be susceptible to errors of a similar nature, and might make underestimations or overestimations of distance, depending on whether they are stationary or in motion at the time they make their estimate.

Passage of Time Estimation and Music

Stimuli that alter perception of passage of time are critical to driver safety. In determining whether music is an important stimuli, it is necessary to consider what an effect on passage of time estimation looks like, whether music has an effect these estimations, and how likely it is for music to be present in a vehicular context. When a stimulus has decreased the perceived duration of time, it means that there has been an underestimation of the passage of time. Figure 1 provides a graphic depicting this relationship:

Figure 1. Relationship Between Stimulus Duration, Passage of Time, and Time to Arrival.



For example, a driver might decide that they have 4 seconds until a vehicle will reach them, direct their attention elsewhere on the roadway, and perceive that only 2 seconds have passed, when in reality, more time has elapsed, bringing the oncoming vehicle closer to the driver than they estimated it would be; if the driver has decided to complete their turn, there may be a collision. People may be susceptible to errors in their estimations of the passage of time. People tend to underestimate the passage of time (e.g. 'time' flew) while playing slot machines, but the presence of music decreased this effect (Noseworthy & Finlay, 2009). In contrast, Droit-Volet et al. (2010) tested musical pieces in major and minor keys to determine whether the emotion (operationalized as tonality) of a musical stimulus had any effect on duration perception. They discovered that, contrary to their hypothesis, there was no difference in estimated duration for either tonality; instead, the presence of any music at all made the stimulus duration seem shorter than it actually was, suggesting that 'time' flies when people are listening to music. Further research into the time-altering qualities of music has shown that lower frequency tones led participants to estimate test durations as being longer than they actually were, effectively slowing 'time' down (Lake et al., 2014). This effect was not reported for mid-range or high frequency tones, which could mean that certain genres of music may be more or less effective at altering the perception of time passage and ultimately the safety of a driver. Though relatively little research has been done on the tempo of music and its effect on passage of time estimations, Oakes (2003) found that for durations between 4 and 15 minutes, slow tempo music led people to underestimate the passage of time, while fast tempo music led to overestimations. It is worth noting that this research used people in a waiting room and considered durations far longer than those which a driver would be exposed to when making estimations of TTA, so it is possible that fast-tempo music may decrease perceived stimulus durations in shorter-term contexts.

The likelihood that music is a stimulus for drivers is very great; listening to music is a behavior that at least two thirds of all drivers report engaging in while in their vehicles (Brodsky & Slor, 2013, as cited in Dibben & Williamson, 2007). This suggests that it is not unreasonable to imagine the presence of music contributing to TTA estimations by altering passage of time estimations.

Time-to-Arrival Estimation

People are prone to errors in TTA estimation, especially involving smaller motor vehicles such as motorcycles. TTA estimation research is typically conducted through the presentation of a target stimulus which is occluded with a masking screen at a specific time prior to its arrival at a specified location. In a non-vehicular context, Landwehr et al. (2013) presented their participants with computer-generated disks that changed in size and found that when the disks were increasing in size (to appear as though they were approaching the participant) participants overestimated the time to collision of the disk by an average of half a second when they were exposed to the moving disk for durations between 1 and 3 seconds. Chang and Jazayeri (2018) examined the modality of the components of time to contact estimations in a digital presentation of a partially-occluded moving bar and found that, whenever available, people integrate temporal cues with speed and distance cues to make better estimations of time to contact. In a vehicular context, Horswill et al. (2005) found evidence of a size-arrival effect, where smaller vehicles were estimated to arrive later than larger vehicles. This may reflect the influence of size- and distance-constancy illusions as discussed above. Further research into the size-arrival effect has suggested that, when considering distance and speed perception, misestimations of speed, rather than errors in distance judgement, are responsible for the overestimation of arrival times for smaller motor vehicles (Lee & Sheppard, 2017).

Simulated Driving Conditions

The presentation of video recordings in lieu of live vehicular testing has reliably produced the same effects as field testing on speed estimation and time-to-arrival estimations. It is worth noting that the usage of the word ‘reliable’ in this context does not necessarily mean accurate, but rather is an indicator of the consistency of the estimations subjects provide. Cœugnet et al. (2013) found that subjects were able to consistently estimate vehicular speed from video footage. Time-to-arrival estimations can be made from computer-presented videos with similar consistency, where subjects are placed in the viewpoint of an observer on the side of the road looking down a curve (Horswill et al., 2005). Pletcher and Ostrofsky (2017) also reported estimations of speed from digital video footage which were consistent with variations in the actual speed of the vehicle while maintaining the directionality of the previously-mentioned biases of speed estimation; see Appendix B for a reproduction of these results.

Current Study

The current study sought to assess the impact of the tempo of music on errors in TTA estimations. To reiterate the components of TTA estimation as discussed earlier, speed and distance are utilized to create an estimation of how much time it will take for a target to reach a specific destination. This estimate may be accurate, but if perception of the passage of time is not accurate, it is still possible for people to make errors in TTA estimation. As noted above, speed and distance estimations both tend to be inaccurate, which means that TTA estimations should already have some degree of inaccuracy regardless of an effect of time perception, which is evident (Horswill et al., 2005; Lee & Sheppard, 2017). Setting the underlying (and better researched) components aside, the effect of alterations of time perception on TTA estimation remains unclear. Though there is research on the effects of music on speed estimation, there is relatively little literature on tempo's potential influence on TTA through the mechanism of time perception, especially in an applied vehicular context. To better examine this and the possible effects of music on speed estimations as a TTA component, two tempi and a control group were tested to determine whether the tempo of drivers' musical selections has any impact on the accuracy of their estimates. Participants estimated the time-to-arrival of a target vehicle from footage presented in the laboratory on a computer while listening to music. The current study manipulated musical tempo, vehicular speed, and masking duration.

To measure the effect of tempo on TTA estimation, participants were placed in one of three tempo conditions: no music (control), a 70 beats per minute (low tempo) track, or a 136 beats per minute (high tempo) track. These tempos were selected based on previous research which suggested that 70 beats per minute and 130 beats per minute are reliable, detectable operationalizations of slow and fast tempo, respectively (Cassidy & MacDonald, 2010). Subjects were randomly assigned to one tempo condition for the duration of the experiment. Musical stimuli were presented through over-the-ear headphones and played while participants watched a randomized series of videos of a car traveling toward them at 25 and 45 miles per hour. A one and two second masking screen applied to these videos forced participants to estimate the time at which the car would have reached them, and differences in these estimations were analyzed to determine the impact of tempo on time-to-arrival estimation, which was measured in milliseconds. It was hypothesized that the high-tempo track would decrease the perceived stimulus duration and therefore result in an overestimation of the time-to-arrival of the vehicle.

Method

Participants

Thirty-six Rutgers University Camden undergraduate psychology students participated in the experiment. Though an initial sample size of 96 individuals was anticipated, the unprecedented COVID-19 pandemic curtailed data collection before this number could be reached. Demographic information was not collected for this experiment. Of the 36 participants, 16 were assigned to the control (no music) tempo condition, 10 were assigned to the low tempo condition, and 9 were assigned to the high tempo condition. All participants were provided course credit as compensation for participating in this study.

Materials

Participants were asked to estimate the time-to-arrival (TTA) of the experimental car by pressing a key on the keyboard in front of them. Participants were tested in a laboratory setting in front of a computer, where they performed 5 practice trials (where no data was recorded) and then provided estimations for 200 silent video clips of the experimental car. For the purposes of accurate stimulus presentation and data collection, the MATLAB package PsychToolBox (PTB) was used. PsychToolBox is a package for MATLAB which provides a variety of functions and objects designed for psychometric experiments; chiefly of use in this study were functions related to the precise rendering and display of videos and the recording of reaction time associated with these videos. The experimental videos depicted the experimental car, a grey Kia Soul, driving with its headlights off in the opposite lane on a two-lane road toward the camera. See Appendix A for an illustration of the scenery and vehicle used in the clips. In each video, the experimental car remained at a constant speed throughout the duration of the clip. There were four different videos presented to participants over the course of the experiment: all possible combinations of two speeds, 25 and 45 miles per hour, and two masking durations, one and two seconds before arrival. The black masking screens were created by editing the videos to remove the video track and replace it with a black screen at either one or two seconds before the vehicle reached participants. These durations were chosen to resemble the shifting of visual attention which occurs at intersections where a driver must look in both directions of traffic before completing a turn. The presence of this black masking screen forced participants to estimate the time at which the vehicle would have reached the edge of the screen. The distance from the participant at which the vehicle begins in each clip is standardized at 500 feet, which renders the duration of the clips variable at the expense of holding constant the distance the vehicle has to travel to the target. This was done to more closely emulate field experience; it is more likely that drivers would be exposed to variable car speeds from a constant sight distance in daily experiences (i.e. waiting at an intersection where a curve in the road prevents cars from being seen until they are a given distance away).

While making estimations, participants listened to one of three possible tempo conditions on over-the-ear headphones. The music used for manipulations of the tempo stimulus was an edited version of the song "Airto" by the group Man Sueto.[1] The song is an instrumental jazz-fusion piece which was selected for its steady rhythm-line, engaging melody, and moderately complex overall listening experience. Its relative obscurity made it unlikely that participants had heard this song before. The song was edited to remove the intro and outro sections, wherein the rhythm is not consistent, and the volume fades out, respectively. Furthermore, it was modified by including a section from the beginning of the song at the end, in order to make the point at which the song repeated less noticeable to participants. Once these edits were made, two version of the song were created for the experiment. One version had a tempo of 76 beats per minute, and the other had a tempo of 136 beats per minute, both of which were engineered in the open-source audio editing

[1] As noted in 17 U.S.C. § 107 (2018), "the fair use of a copyrighted work…for purposes such as…scholarship, or research, is not an infringement of copyright," which obviated the need to obtain rights or permission to use this music.

program Audacity to prevent the audio from sounding distorted as a result of altering the playback speed. The addition of the control group in this experiment allowed for the detection of an effect due to the presence of music regardless of tempo.

Procedure

Participants signed a consent form, and then watched a total of 200 clips of a vehicle travelling toward the camera in the opposite lane, designed to imitate an oncoming vehicle. Participants were randomly assigned to one of three music tempo conditions (no music, low tempo, or high tempo), and the track for their assigned condition played continuously through headphones until all trials were completed. The programming software MATLAB was used to load the psychometric package PsychToolBox, which was used to present the four video samples as well as to record participants' TTA estimations. In the stimulus presentation code, one of four videos was selected at random and displayed for the participant. A timer counted up from the initial frame of the video, and this timer (and the video presentation) ended once subjects had provided their TTA estimation. Participants made their TTA estimations by pressing the space key on their keyboard at the time they believed the vehicle (which was obscured by the one or two second mask) had reached the edge of the screen. Milliseconds was the unit of measure used for their responses. The actual TTA of the vehicle was subtracted from participants' estimations to determine the estimation error. A positive TTA estimation error indicated an estimation which occurred after arrival (an 'unsafe' estimate), while a negative estimation error indicated an estimation which occurred prior to arrival (a 'safe' estimate). To help prevent task fatigue, the experiment was broken into four blocks with 50 video presentations each, where each block was ended with a two-minute rest period before subjects entered the next block. No feedback regarding participant estimation accuracy was provided.

Data Screening

Due to the research design, participants provided 50 TTA estimates for each of the four videos for a total of 200 estimates per participant. It was anticipated that, for some trials, participants would potentially miss a response due to inattention or distraction. To account for this, 352 responses with an error greater than 5000 milliseconds were excluded from subsequent analyses. This resulted in the exclusion of 4.89% of the data and reduced the overall number of observations from 7200 to 6848. For one participant from the no music condition, more than half of their estimations exceeded this cutoff; the participant was removed from subsequent analyses, further reducing the data down to 6778 observations.

Results

Following the data screening process described above, subjects' TTA estimation errors were averaged within blocks. Due to the presence of both between-subjects (tempo condition) and within-subjects (masking condition and speed) variables, a mixed ANOVA was conducted. Testing block was included in this ANOVA to check for differences in reaction time over the duration of the experiment. There was no significant difference in TTA estimation error by testing block, F (2.08, 66.44) = 3.00, $p > .05$. Descriptive statistics for each of the tempo, speed, and masking conditions are displayed in Table 1.

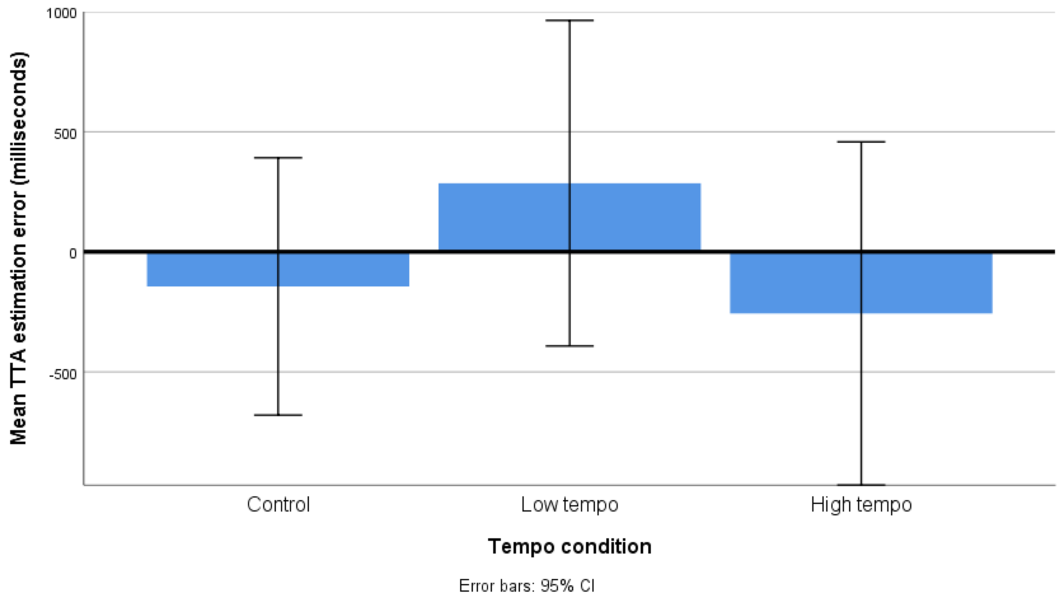
Table 1. Mean (SD) Time-to-Arrival Estimation Error Values

	One Second Mask		Two Second Mask	
Tempo	**25 MPH**	**45 MPH**	**25 MPH**	**45 MPH**
Low	232.50 (606.85)	338.89 (757.81)	120.72 (885.49)	439.21 (994.80)
High	-70.81 (882.29)	-22.36 (1009.56)	-289.35 (1059.37)	-145.66 (1130.06)
Control	-312.81 (1517.42)	69.24 (1088.55)	-371.60 (1569.63)	86.47 (1381.05)

Analyses Pertaining to the Effects of Tempo

A mixed ANOVA was conducted using tempo condition, masking condition, speed, testing block, and TTA estimation error. There was no significant effect of tempo on TTA estimation error, F (2, 32) = .75, $p > .05$. Figure 2 depicts the average TTA estimation error for each tempo condition.

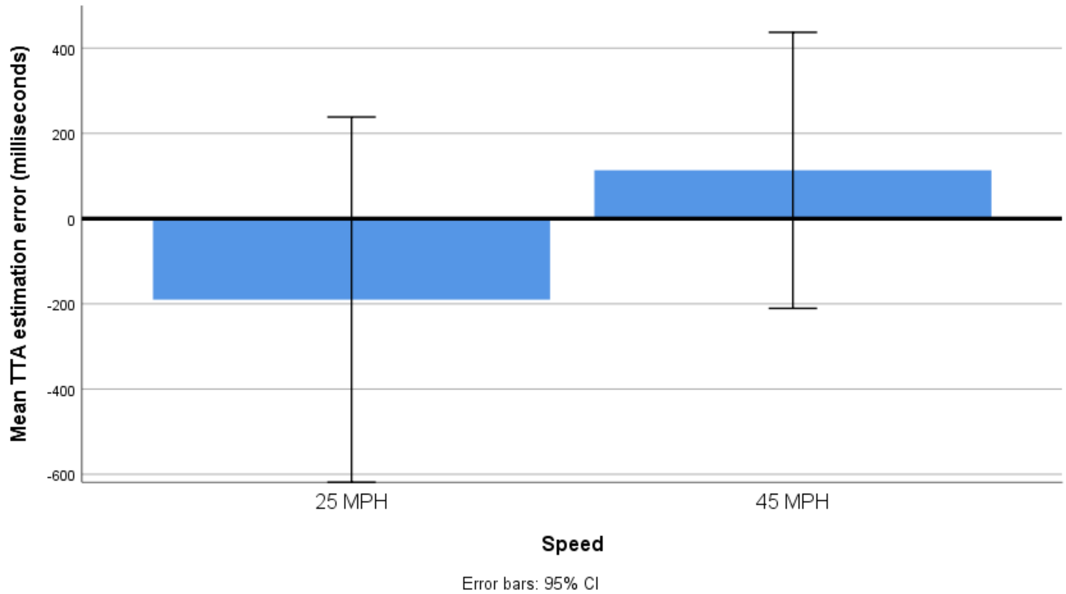
Figure 2. TTA Estimation Error by Tempo Condition



Additional Analyses

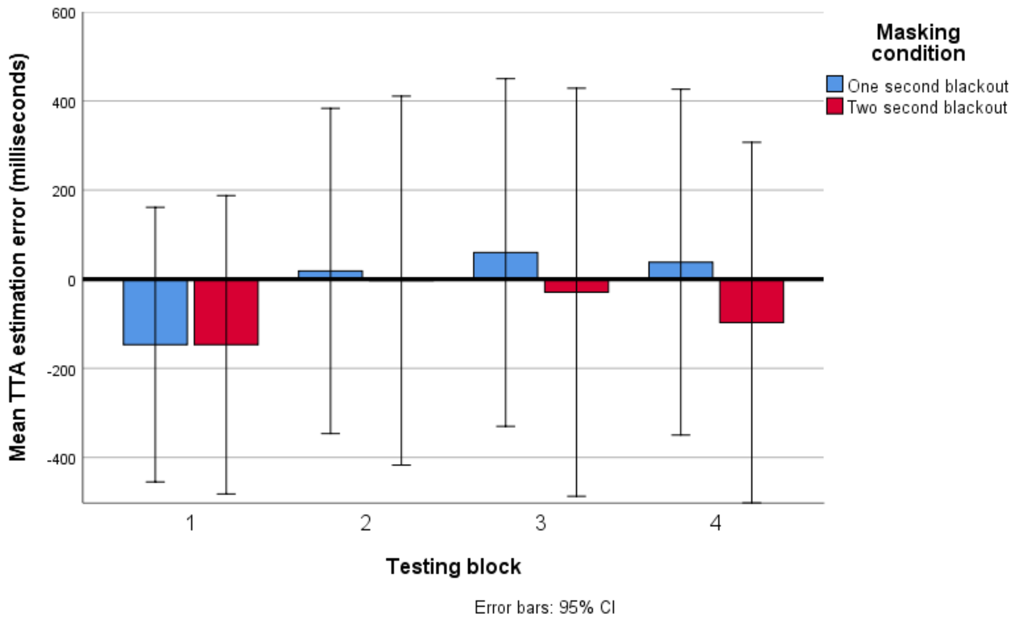
The variables speed and masking condition were included in the mixed ANOVA to explore the potential of other variables to interact with tempo and influence TTA estimations. There was a significant effect of speed on TTA estimation, F (1, 32) = 21.29, $p < .001$. People tended to make early (safe) estimations at a slower speed and late (unsafe) estimations at a higher speed. Figure 3 depicts the average TTA estimation error for the two vehicle speeds.

Figure 3. TTA Estimation Error by Speed



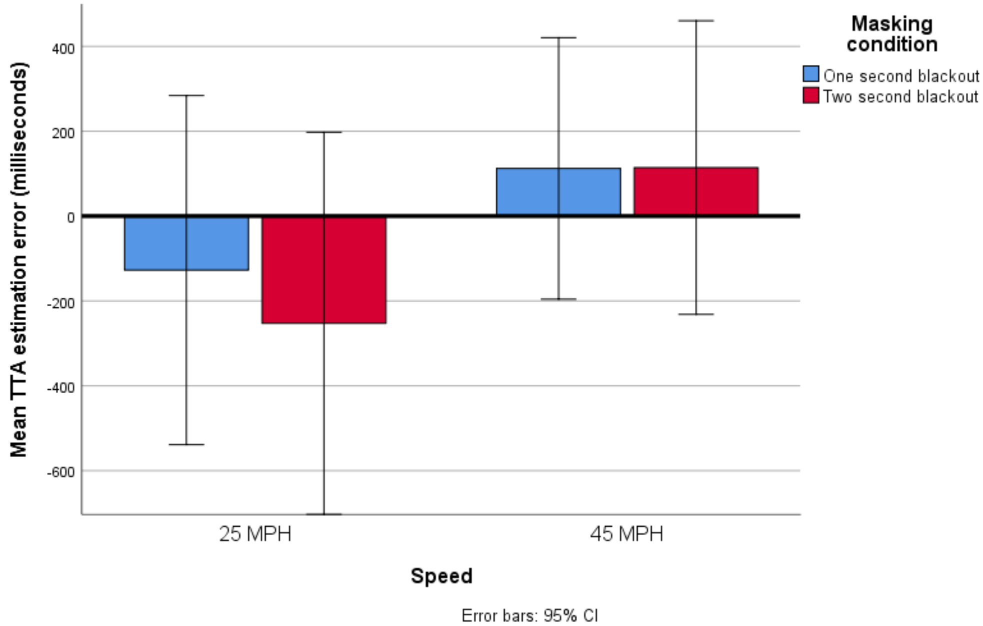
There was a significant interaction between testing block and masking condition, F (3, 96) = 3.08, p = .03. Participants tended to make early estimations for both masking conditions in the first testing block and continued to make early estimations only in the two second masking condition. Figure 4 depicts the average TTA estimation error for the two masking conditions across all of the testing blocks.

Figure 4. TTA Estimation Error by Testing Block and Masking Condition



There was also a significant interaction between speed and masking condition, F (1, 32) = 7.64, p = .01. TTA estimation error was similarly late between both masking conditions at high vehicle speed, but at low vehicle speed, the two second masking condition produced much earlier estimations. Figure 5 depicts the average TTA estimation error for the two masking conditions in both of the vehicle speed conditions.

Figure 5. TTA Estimation Error by Speed and Masking Condition



Discussion

In summary of the results described above, participants' estimations of TTA were not significantly affected by musical tempo. Speed did have an effect on TTA estimation, and there was an interaction between masking condition and testing block, as well as masking condition and speed. The results of this research failed to provide support for the hypothesis presented earlier. Participants in this study did not demonstrate the tendency for overestimation in time to arrival noted by Landwehr et al. (2013) and Lee and Sheppard (2017). The current study also contradicts findings from Chang and Jazayeri (2018), calling into question the notion that, in addition to distance and speed information, people also incorporate temporal information into their estimations of TTA. It is possible that, contrary to findings from Droit-Volet et al. (2010) which suggest that music leads to underestimations of stimulus duration (i.e. 'time' flies), there is no effect of music on time perception, but the current study lacks the ability to determine whether this is true. The results of the present study suggest that any effects of tempo on passage of time estimations do not translate to effects on estimations of TTA. This means that TTA estimation errors may not be affected by the music people choose to listen to while driving.

There was a significant interaction between masking condition and testing block, such that TTA estimations were nearly identical between masking duration in the first block, and then different in magnitude in all other blocks. This is likely due to acclimation to the study process. Future studies might consider the inclusion of a longer trial period prior to data collection. There was also a significant interaction between speed and masking condition which was rather counterintuitive; because both videos held the distance the vehicle traveled constant, the 45 mile per hour video was shorter than the 25 mile per hour video. One would expect to see a difference as a result of masking duration for the shorter (faster speed) video, where two seconds is a larger percentage of occlusion time relative to the whole video. Instead, the difference is in the longer (slower) video, though the direction of this difference is less surprising: the one second occlusion led to more accurate TTA estimations than the two second occlusion.

Additionally, the current study found a relation between vehicular speed and TTA estimation error. Subjects tended to estimate an early arrival when the target vehicle was approaching slowly and a late arrival when it was approaching quickly, suggesting an inflation of perceived speed in the 25 MPH condition and a deflation of perceived speed in the 45 MPH condition, consistent with findings from Pletcher and Ostrofsky (2017). It is unclear whether more extreme speeds produce errors of the same magnitude and direction as those found in the current study, and it is also unclear if there is an 'optimal' speed, where TTA estimation error is at a minimum. Evidence of such a speed would be a strong case for modifying speed limits near intersections, for example, in the hopes of reducing accidents which arise as a result of overestimating the TTA of an oncoming vehicle.

Limitations

Although steps were taken to limit participants’ awareness of the other conditions of the experiment to which they were not assigned, they were not assessed at the end of the session to ascertain whether they were aware of the hypothesis being tested. Furthermore, it is possible that some participants may have had an emotional valence toward or previous exposure to the music stimulus used in this experiment. The experimental procedure itself was designed to replicate a field experience as closely as possible, but the repetitive nature of the data collection process may have detracted from this realism, and the practice trials at the beginning of the experiment may have been insufficient to acclimate participants to the testing process. The design of this study prevents the examination of whether musical tempo affects time perception, which would lend clarity to the larger question of whether time perception affects TTA estimation. Additionally, the study does not provide adequate resolution on any potential non-linear effects of speed on TTA estimation. The inclusion of an additional speed, such as a 65 mile per hour condition, and an additional tempo condition, such as a 100 beats per minute track, would help to create a clearer picture of the nature of the significant effects on TTA estimation found in this experiment.

Concluding Thoughts

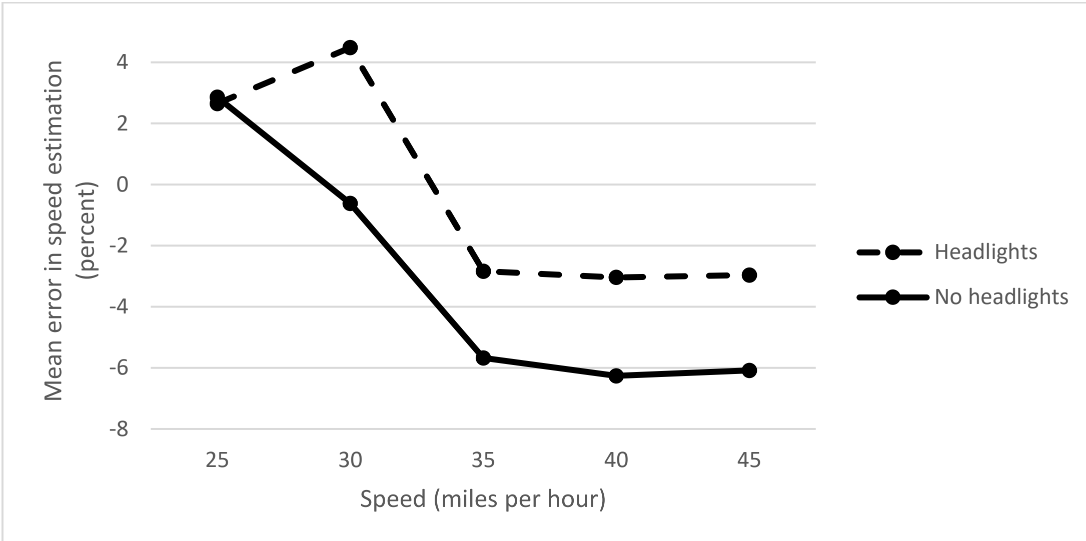
While TTA estimation is not particularly sensitive to influence from musical stimuli, there is clear evidence that vehicular speed can affect estimates, which in turn affects driver safety. The current study does not provide support for a model of TTA estimation where errors can be produced by the inclusion of a musical stimulus, but it does reinforce the importance of speed perception and the necessity of understanding what steps can be taken to reduce errors in speed estimation. Future studies might explore the linearity of errors in TTA estimations as a result of varying speeds and test for an ‘optimal’ speed which minimizes estimation errors; it would also be valuable to include a measure of time perception in addition to TTA estimations to determine whether TTA estimations are sensitive to errors or alterations in passage of time estimations.

Appendix A

Still image depicting the target vehicle and scenery from video clip

Appendix B

Reproduction of a graph of speed estimation errors from Pletcher and Ostrofsky (2017)



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