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DOI

[10.1016/j.trf.2018.02.031](https://doi.org/10.1016/j.trf.2018.02.031)

Publication date

2018

Document Version

Final published version

Published in

Transportation Research Part F: Traffic Psychology and Behaviour

Citation (APA)

Stelling-Konczak, A., Vlakveld, W. P., van Gent, P., Commandeur, J. J. F., van Wee, B., & Hagenzieker, M. (2018). A study in real traffic examining glance behaviour of teenage cyclists when listening to music: Results and ethical considerations. *Transportation Research Part F: Traffic Psychology and Behaviour*, 55, 47-57. <https://doi.org/10.1016/j.trf.2018.02.031>

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A study in real traffic examining glance behaviour of teenage cyclists when listening to music: Results and ethical considerations



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ARTICLE INFO

Article history:

Received 7 June 2016

Received in revised form 11 February 2018

Accepted 28 February 2018

Available online 14 March 2018

Keywords:

Cycling safety

Music

Auditory perception

Visual attention

Visual performance

Research ethics

ABSTRACT

Listening to music while cycling impairs cyclists' auditory perception and may decrease their awareness of approaching vehicles. If the impaired auditory perception is not compensated by the cyclist himself or other road users involved, crashes may occur. The first aim of this study was to investigate in real traffic whether teenage cyclists (aged 16–18) compensate for listening to music by increasing their visual performance. Research in real traffic may pose a risk for participants. Although no standard ethical codes exist for road safety research, we took a number of ethical considerations into account to protect participants. Our second aim was to present this study as a case study demonstrating ethical dilemmas related to performing research in real traffic. The third aim was to examine to what extent the applied experimental set-up is suitable to examine bicyclists' visual behaviour in situations crucial for their safety. Semi-naturalistic data was gathered. Participants' eye movements were recorded by a head-mounted eye-tracker during two of their regular trips in urban environments. During one of the trips, cyclists were listening to music (music condition); during the other trip they were 'just' cycling (the baseline condition). As for cyclists' visual behaviour, overall results show that it was not affected by listening to music. Descriptive statistics showed that 21–36% of participants increased their visual performance in the music condition, while 43–64% decreased their visual performance while listening to music. Due to ethical considerations, the study was therefore terminated after fourteen cyclists had participated. Potential implications of these results for cycling safety and cycling safety research are discussed. The methodology used in this study did not allow us to investigate cyclists' behaviour in demanding traffic environment. However, for now, no other research method seems suitable to address this research gap.

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1. Introduction

Listening to music is popular among cyclists in, for example, the Netherlands and Sweden, especially among youngsters. In Dutch surveys listening to music was reported by about three quarters of adolescent cyclists (Goldenbeld, Houtenbos,

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Ehlers, & de Waard, 2012; Schroer, 2014; Stelling-Konczak, Hagenzieker, & Van Wee, 2014), 42% of young adults and only 6% of the elderly (65 years or older) (Stelling-Konczak & Hagenzieker, 2014). Both in Sweden and in the Netherlands, listening to music was found to be the most common technology-related activity among cyclists (Adell, Nilsson, & Kircher, 2014; Stelling-Konczak & Hagenzieker, 2014). Research shows that listening to music negatively affects cycling behaviour. Observational studies found that cyclists listening to music disobeyed traffic rules more often (de Waard, Schepers, Ormel, & Brookhuis, 2010) and engaged in unsafe behaviours more frequently than those not performing a secondary task (Terzano, 2013). Furthermore, the results of a field experiment show that cyclists' auditory perception deteriorated when they were listening to music. Even moderate volume or moderate tempo music compromised cyclists' perception of bicycle bells: more than 60% of cyclists listening to music did not hear the bells. Loud music, high tempo music, and particularly music listened through in-earphones impaired even hearing of loud sounds (i.e. horn honking). Cyclists' auditory perception was not affected only when music was listened to through one earphone. Finally, cyclists rated listening to music while cycling as more risky than "just" cycling. The higher the risk perception, the lower the frequency of listening to music. (de Waard, Edlinger, & Brookhuis, 2011; de Waard et al., 2010).

Two potential explanations can be found for these negative effects. Music, especially loud music, can mask traffic sounds. Quieter sounds are generally masked by louder sounds. The higher the sound intensity of the masking sound (e.g. music), the higher the intensity level of the masked sound (e.g. traffic sounds) must be before it can be detected (see e.g. White & White, 2014). Masking is, furthermore, more likely to occur when music contains similar frequency ranges as traffic sounds (White & White, 2014). Music can also distract attention from the environment toward inward experiences (thoughts, memories, emotions, moods) (see for example Herbert, 2013). Fundamental research found a reduction in eye movement activity (longer fixations, fewer saccades and more blinks) while listening to music, suggesting a decrease in vigilance under the influence of music (Schäfer & Fachner, 2015).

There are, however, some indications that cyclists compensate for listening to music by adapting their behaviour. In a Dutch survey two-thirds of teenage cyclists reported using adaptive strategies to compensate for listening to music (Stelling-Konczak & Hagenzieker, 2014). Increasing visual attention was found the most often reported type of compensatory strategy among Swedish and Dutch adolescents (Adell & Nilsson, 2014; Stelling-Konczak & Hagenzieker, 2014). However, a Swedish field experiment where an eye-tracker was used, found no change in visual behaviour among cyclists who were listening to music (Ahlstrom, Kircher, Thorslund, & Adell, 2016). Similarly, Dutch field experiments showed that a number of objects (printed traffic signs and a clock) noticed by cyclists was not influenced by listening to music (de Waard et al., 2011, 2014). However, in these two latter studies visual behaviour was not directly measured. Instead, after each trip, cyclists were to report noticing the objects. Since the reporting took place after the trip, failure to mention the objects may have reflected cyclists' memory deficits instead of deficits in visual perception. Furthermore, the objects used in the studies were irrelevant for the traffic task.

The discrepancies between the findings from surveys and research performed in real traffic may be a result of the different methodologies employed and reflect the difference between what cyclists think they do and their actual visual behaviour. In the Dutch survey cyclists were asked to provide information about what they typically do while cycling with music. Furthermore, surveys rely on accuracy of memory and honesty of reporting and may reflect what people think they do, rather than their actual visual behaviour. In the field experiment of Ahlstrom, the actual visual behaviour in one specific traffic environment was monitored with an eye-tracker. The traffic environment studied consisted of a combined sidewalk/cycle track alongside an urban street and physically separated from the street. The cycle track intersected four side roads to the right, where the track had priority over the side roads. The route was situated in a semi-industrial area where traffic densities were low to moderate. It can therefore be concluded that the traffic environment in the Swedish field experiment was relatively undemanding for cyclists. The results of the study leave open the possibility that cyclists who listen to music adapt their visual behaviour only in some situations, e.g. more demanding traffic situations. Therefore, the authors recommended performing a similar study in other traffic environments. Compared to self-reported data, monitoring cyclists' behaviour in real traffic by means of an eye-tracker is better able to provide quantitative evidence on the location and duration of one's visual effort. However, studies in real traffic can be problematic from an ethical point of view.

1.1. Ethical considerations

Research in real traffic generates important ethical issues as it can lead to increased risks for cyclists. Cyclists are vulnerable road users: contrary to car occupants, cyclists are unprotected by an outside shield. Cyclists have also a higher risk of injury or death¹ than car occupants (ITF, 2013). Furthermore, as research has shown that listening to music is potentially risky for cyclists, those who engage in this activity may be at a higher risk than cyclists who 'just' cycle. Even if cyclists themselves accept risks in real traffic and decide to listen to music while on the road, it does not directly justify the researchers to inflict the same level risks on participating cyclists (see Svensson & Hannson, 2007).

Therefore, it is of primary importance that researchers protect cyclists participating in an on-road study. This requires researchers to minimize the risks and to continually monitor the ongoing research for safety threats. If harmful results manifest, researchers should be prepared to terminate the study (see Svensson & Hannson, 2007). The need to interrupt a study,

¹ risk of injury or death = number of injured cyclists respectively cyclist deaths per distance travelled.

although desirable from the ethical point of view, may however threaten researchers' goal to conduct a 'publishable' research with statistically significant results. Statistically significant results are generally treated as more important than nonsignificant ones in many research fields: journal editors and reviewers tend to reject studies with non-significant results (Fanelli, 2011). This publication bias has a number of consequences, e.g. impoverishment of research creativity, favouring predictable results at the expense of pioneering, high-risk studies, increased prevalence of research bias and misconduct or over-interpretation of results (see e.g. Fanelli, 2011). In addition, non-significant results should be published so that other researchers do not waste their time and money for unnecessary repetition. As the likelihood of obtaining significant findings is also related to sample size, researchers often feel encouraged to recruit enough participants to get a sufficient statistical power in order to detect an effect if there actually is one.

Ethical approval is generally not mandatory for traffic safety research. To the best of our knowledge at the time of writing of this paper (January 2018) scientific journals for transport safety do not require a submission including human participants to be ethically approved. According to Svensson and Hansson, only a part of road safety research is subjected to ethical supervision (2007). A large part of road safety research, especially research performed outside universities, is carried out without the approval of ethics committees. In contrast universities nowadays tend to require ethical review for the approval of research. However, various ethical committees do not always reach the same conclusions, as shown for medical research (Edwards, Stone, & Swift, 2007). Anecdotal evidence for inconsistencies in ethical review between various ethics committees is also known in the field of road safety research. To promote equal opportunities for researchers who aim to conduct an empirical study and to minimize risks which may arise when people participate in research, ethical codes for traffic research need to be created. According to Svensson and Hansson ethical codes which have already been developed for other fields of empirical research (e.g. biomedicine and psychology) can be useful for application in the field of traffic research.

1.2. This study

The current study was designed to extend previous research into visual behaviour of cyclists who listen to music. The first aim of the study was to examine to what extent listening to music affects glance behaviour of teenage cyclists. Teenage cyclists were of interest, since they listen to music more often than cyclists of other age groups. Furthermore, teenagers are particularly vulnerable from the perspective of cycling safety. There is a peak in cyclist fatalities among teenagers aged between 12 and 17, the age of increasing cycling autonomy (Candappa, Christoph, van Duijvenvoorde, Vis, et al., 2012). In the previous studies into cyclists' visual behaviour (Ahlstrom et al., 2016; de Waard et al., 2010, 2011) the participating cyclists were older (range 16–26 years old). Teenagers, due to the immaturity of their brains and the great influence of the social environment, tend to take more risks in traffic than older road users (see e.g. Twisk, 2014). The visual behaviour of teenage cyclists may therefore also differ compared to older cyclists.

We chose to perform a study in real traffic and to use an eye-tracker to monitor cyclists' visual behaviour. This choice was dictated by the aspiration to obtain ecologically valid results and to determine location and duration of cyclists' visual effort. Other available research methods, including a field study or an observational study, could not be used due to a number of disadvantages. To start with, due to practical reasons observational studies are usually conducted at a limited number of locations and for a limited period of time, which can reduce the generalisability of results. Additionally, it is not always easy to determine whether the observed cyclist is listening to music, e.g. earbuds may not always be visible. Finally, with this method cyclists' visual attention can be determined only roughly, i.e. using head turns instead of eye movements. An eye-tracker is considered as an appropriate research tool to identify road users' visual attention (Velichkovsky, Rothert, Miniotas, Dornhoefer, et al., 2003). Although attention can be directed without moving the eyes, eye movements and visual attention are linked in most cases (see e.g. Mancas & Ferrera, 2016).

Secondly, we aimed to present our study as a case study explicitly addressing ethical issues related to performing an on-road study and to demonstrate dilemmas and consequences of this approach. Our focus is ethical issues related to protecting the welfare of research participants. Other ethical aspects, such as setting priorities for road safety research, although also important are beyond the scope of this paper. A number of ethical considerations were taken into account in the present study in order to minimize the risks. For example, participants used their own bicycles and they were also free to choose their routes, departure and travel time – see Section 2.1 for all ethical considerations applied in this study.

The third aim of the study was to examine to what extent the experimental set-up applied in this study is suitable to examine teenage bicyclists' visual behaviour in situations crucial for their safety. Unlike the study of Ahlstrom et al. where participants cycled along the same route, our experimental set-up allowed us to collect semi-naturalistic data of high ecological validity. Such an approach makes it possible to observe participants in a natural environment (Dozza, Werneke, & Fernandez, 2012; Gehlert, Kühn, Schleinitz, Petzoldt, et al., 2012) but at the same time, it does not allow for control of the traffic environment. Therefore, it may be challenging to gather sufficient data on situations crucial for cycling safety. The present study aimed to evaluate this aspect. Another aspect investigated in this study was the performance of the eye-tracker and the quality of the data. The use of an eye-tracker in a natural setting can be challenging due to the fact that infra-red light of the sun can deteriorate the eye-tracker's capability to capture saccades (see e.g. Vansteenkiste, 2015). Therefore, in this study we also investigated the performance of the eye-tracker and the quality of the data.

2. Methods

2.1. Ethical considerations

For this study we applied stringent ethical criteria. In the Netherlands it is not mandatory for research institutes to obtain an ethical approval for the studies they perform. In 2015 SWOV Institute of Road Safety Research in the Netherlands, where the present research was conducted, decided however to establish an ethics committee. Precisely at the time when the data collection was about to start, an ethics committee was under development at our institute. For this reason, we were particularly aware of ethical considerations related to performing research with human participants. First, cyclists were included if they cycled regularly and if they frequently listened to music while cycling. Next, all participants (and in case of participants younger than 18 years old additionally their caregivers) signed an informed consent and could stop at any time during the experiment. Furthermore, the participants used their own bicycles and they were free to choose their route, departure and travel time. Finally, data collection was done in phases. After the first phase comprising 6 participants, preliminary analysis was performed to check whether cyclists compensate for listening to music by increasing their visual performance. Given the small number of participants, this phase gave us just an indication of the expected results. The final decision considering whether or not to continue the data collection was therefore taken after the second phase in which the data of additional 8 participants was gathered. In case of adverse results, we were prepared to terminate the study. The target number of participants was at least 20 cyclists.

During the time of data collection we also carried out a literature study of research, field experiments and naturalistic cycling studies, performed with cyclists in real traffic. Our objective was to compare ethical considerations possibly addressed in previous studies with the ones we took into account in the present study – see Section 3.1.1.

2.2. Main experiment: effect of listening to music on cyclists' visual behaviour

2.2.1. Participants

Participants were recruited from a secondary school in the vicinity of SWOV Institute for Road Safety Research (The Hague, The Netherlands), through flyers and via informal contacts. Each participant received a gift voucher of €25.

2.2.2. Equipment and software

Eye-movements were recorded with a mobile eye-tracking headset (Pupil Pro, see (Kassner, Patera, & Bulling, 2014) consisting of two built-in cameras (see Fig. 1). A small and lightweight eye camera recorded the left eye at 30 Hz. A scene camera with a 90-degree horizontal field of view, mounted above the user's eye, recorded the forward road scene at 30 Hz. Both cameras were connected to a laptop which was carried in a rucksack. The data from the eye and the scene camera were combined using Pupil Software into one video file showing the scene camera footage with the glance data superimposed on the scene camera footage. Kinovea software (version 08.15) was used to extract, frame by frame, the duration of glance directions (Kinovea, 2014).

2.2.3. Design and procedure

A within-subject design was used. Cyclists' glance behaviour, during two of their regular trips in urban environments, was monitored by a head-mounted eye-tracker. All trips were made in The Hague area. The route of the two trips was identical for a given participant (for example from home to school) but varied across the participants. During one of the trips, cyclists were listening to music of their choice and at their preferred volume (*music condition*); during the other trip they were 'just' cycling (*baseline condition*). The order of the conditions was randomised across participants. The data were collected by daylight and in dry weather. At the start of the route, the equipment was attached to the participant and the eye-tracker was calibrated. At the end of the route, the equipment was dismantled. After the second trip, the participants filled in a questionnaire including demographic measures (sex, age, and education), cycling habits, subjective risk perception and engagement in risk behaviour and incidents. Respondents were also asked to indicate how much they can hear when listening to music while cycling and how much a cyclist should hear to be able to cycle safely (response options: 1 = *nothing at all*, 2 = *not much*, 3 = *only loud or sharp sounds*, 4 = *most sounds*, 5 = *all sounds*) (see also Goldenbeld, Houtenbos, & Ehlers, 2010; Stelling-Konczak & Hagenzieker, 2014).

2.2.4. Situations crucial for cycling safety

The choice of situations crucial for cycling safety in this study was dependent on which routes were chosen by the cyclists. We aimed for situations which are demanding and potentially risky for cyclists. We decided to focus on uncontrolled intersections, where no traffic lights or signs are used to indicate the right-of-way. Cyclists at uncontrolled intersections should give way to traffic approaching from the right, according to the general rule applying in the Netherlands. There were two reasons for analysing the eye-tracker data at uncontrolled intersections. First, this type of intersections is relevant from the cycling safety point of view due to potential conflicts between cyclists and motorized vehicles. At uncontrolled intersections cyclists are usually not separated from motorized vehicles. This type of conflicts is important to study since young cyclists in the Netherlands are relatively often involved in a crash with a motorized vehicle (Reurings, Vlakveld, Twisk,



Fig. 1. The eye-tracker used in the present study.

Dijkstra, et al., 2012). Second, uncontrolled intersections were present in all routes travelled by the participants, providing us with sufficient data for the analysis. Our study focuses specifically on the glances to the right at uncontrolled intersections. This type of intersections requires cyclists to use their visual and auditory senses to check for the traffic approaching from the right - the direction to which cyclists should give way.

2.2.5. Data analysis

The video files for the music and baseline condition of each participant were examined to extract the segments including uncontrolled intersections. Glances to the right into an intersecting road with a minimum duration of 200 ms were included in the analysis. This duration was chosen as fixations longer than 200 ms can be related to attentive, focal processing while shorter fixations are considered pre-attentive (Velichkovsky, Rothert, Kopf, Dornhöfer, & Joos, 2002). Glance behaviour was not encoded when the cyclist was stationary at an intersection (e.g. while yielding). For one participant, one intersection was excluded due to small changes of the route. For each participant and each uncontrolled intersection three performance indicators of visual behaviour were coded (see Table 1). The quality of the eye-tracker data turned out to be insufficient for only one trip. Therefore, similarly to Ahlstrom et al. (2016), in this case head turns inferred from the scene camera footage were used for this trip to code the cyclist' visual behaviour. Additionally, road infrastructure characteristics and traffic conditions were annotated for each intersection: i.e. presence or absence of a view obstruction, pedestrians, traffic approaching from the right and traffic approaching from the left. Two independent researchers coded the intersections. Twenty percent of the intersections was coded independently by both researchers. The Kappa inter-rater reliability statistic was 0.87 ($p < 0.05$) indicating a substantial agreement. The coders discussed and resolved discrepancies through mutual agreement.

All statistical analyses were conducted using SPSS Statistical Software (version 23). The GENLIMMIXED procedure was used to analyse the influence of music on whether or not a cyclist looked to the right into an intersecting road. Per participant each intersection was scored either 1 (a cyclist looked to the right) or 0 (a cyclist did not look to the right) and therefore the dependent variable was the number of intersecting roads which the cyclist looked into out of the total number of intersections encountered. *Music* and *baseline* condition was the within-subject factor. Since the dependent variable was not a continuous but a binomial variable, a standard repeated measures analysis of variance could not be applied. The generalized linear mixed models (GLMMs) analysis was performed instead with the summed *looking to the right*-score treated as a binomial variable with a logit link function. Generalized linear mixed models (or GLMMs) can be conceived of as a generalization of standard repeated measures analysis of variance models where the dependent variable is not necessarily continuous and normally distributed, but can also be a binary or binomial response, see for example Stroup (2013) for details.

The influence of music on the other performance measures (*mean number of glances* and *mean glance duration*) was analysed using separate standard repeated measures ANOVAs for each performance measure across the two conditions: *music*

Table 1

Performance measures of visual behaviour used in this study.

Looking to the right	The number of intersecting roads to the right at uncontrolled intersections which the cyclist looked into out of the total number of intersecting roads to the right.
Mean number of glances	The summed mean number of glances towards the intersecting roads to the right.
Mean glance duration	The summed mean glance duration (<i>in milliseconds</i>) towards the intersecting roads to the right.

and *baseline* (the within-subject factor). A Wilcoxon Signed Ranks test was used to compare how much sound participants can hear while listening to music with how much sound they considered necessary to cycle safely (which were ordinal variables).

2.3. Evaluation of experimental set-up

2.3.1. Eye-tracker

Eye tracking performance outdoors may suffer from sunlight exposure. To avoid this problem many field studies with an eye-tracker collect data only in cloudy weather. To our knowledge, the performance of the Pupil eye-tracker has not been evaluated yet in an outdoor environment. Therefore, with this study we aimed to fill this gap. The trips were made by daylight and in dry, but not necessarily cloudy weather.

2.3.2. Situations crucial for cycling safety

To investigate whether the uncontrolled intersections encountered by the participants were indeed demanding for cyclists, for each intersection, road infrastructure characteristics and traffic conditions were annotated i.e. presence or absence of a view obstruction, pedestrians, traffic approaching from the right and traffic approaching from the left. Two independent researchers coded the intersections.

3. Results

3.1. Ethical considerations

3.1.1. Literature overview

In total 12 studies, both field studies and naturalistic cycling studies were analysed. Four studies report obtaining ethical approval (de Waard, Lewis-Evans, Jelijs, Tucha, et al., 2014; de Waard et al., 2010, 2011; Vansteenkiste, 2015). In the other eight studies (e.g. Ahlstrom et al., 2016; Dozza, Bianchi Piccinini, & Werneke, 2016; Dozza & Werneke, 2014; Kircher, Ahlstrom, Palmqvist, & Adell, 2015; Langford, Chen, & Cherry, 2015; Salmon, Young, & Cornelissen, 2013; Schleinitz, Petzoldt, Franke-Bartholdt, Krems, et al., 2015; Schleinitz, Petzoldt, Franke-Bartholdt, Krems, et al., 2017), it is not clear whether ethical considerations were addressed: ethical approval is not reported, however, this does not necessarily mean that no ethical scrutiny was carried out.

3.1.2. Main experiment

Descriptive statistics of preliminary data, collected in the first phase of the experiment (based on 6 participants), were similar for the baseline and music conditions. Due to the small sample size, no statistical tests were performed in the first phase. In the second phase, data from additional 8 participants was gathered. The results based on the data gathered in the first and the second phase ($N = 14$) revealed no increase in visual performance while cycling with music (see Section 3.2.2). On the contrary, many participants in the music condition showed a *decrease* in visual performance. Given the adverse results, the experiment was stopped at that point (see also Section 4.1).

3.2. Main experiment: effect of music on cyclists' visual behaviour

3.2.1. Participants

In the end, fourteen cyclists (7 females) aged 16–18 years ($M = 17.1$; $SD = .5$) participated in this study. Participants spent on average about 6.5 h cycling per week ($M = 394$ min). On average, they were listening to music during 70% of all of their trips.

3.2.2. Visual behaviour

The results are based on the data gathered by the whole sample ($N = 14$). Table 2 contains descriptive statistics for the three performance measures analysed in this study. On average less than half of intersecting roads to the right received cyclists' glances ($M = 0.490$ in the *baseline* and $M = 0.406$ in the *music* condition, see Table 2).

None of the performance measures differed significantly between the *baseline* and *music* conditions indicating that cyclists' visual behaviour was not significantly influenced by listening to music.

Table 2
Descriptive statistics: M and (SD) for the three performance measures (see Table 1 for the description of the performance measures.).

	Baseline	Music
Looking to the right	0.490 (0.328)	0.406 (0.296)
Mean number of glances	4.07 (3.7)	3.71 (4.4)
Mean glance duration (in ms)	500.1 (298.5)	648.9 (397.5)

Table 3

Percentage participants who increased or decreased visual performance in the music condition (%).

	Increased visual performance	Decreased visual performance
Looking to the right	21.5	57
Mean number of glances	21.5	43
Mean glance duration (in ms)	36	64

Although overall visual behaviour between the music and the baseline condition was not statistically different, descriptive analysis (see Table 3) showed that 21–36% of the participants increased their visual performance in the music condition. A higher percentage of participants, 43–64% decreased their visual performance while listening to music.

3.2.3. Final results: self-reported measures

Participants indicated that they could hear as much sound as they considered necessary to cycle safely. The Wilcoxon Signed Ranks test revealed no significant differences between the ratings of how much sounds could be heard while listening to music and the ratings of how much sound is considered necessary to cycle safely.

Due to the limited sample size, statistical analyses were not performed to examine the association between glance behaviour and self-reported measures. Computing pairwise correlations between all these variables creates the problem of chance capitalization due to multiple pairwise comparisons. An alternative approach can be performing a categorical principal component analysis (CATPCA). CATPCA is a data reduction technique appropriate for categorical and ordinal variables. It is used to identify the underlying components of a set of items while maximizing the amount of variance accounted for in those items. Since this technique requires 5 to 20 times as many participants as variables, it could not be applied in this study either.

3.3. Evaluations of experimental set-up

3.3.1. Eye-tracker

Results show that although some of the trips took place in sunny weather, the eye-tracking data was not disturbed by the infra-red light of the sun. As already mentioned good quality eye-tracking data was obtained. Only one trip (out of 28) resulted in insufficient quality of the eye-tracking data due to poor calibration.

3.3.2. Situations crucial for cycling safety

On average the trips lasted for 13 min. The number of uncontrolled intersections encountered by the participants varied from 2 to 17 ($M = 7.6, SD = 4.6$). At the intersections cyclists either went straight on (in 85% of all intersections) or turned left.

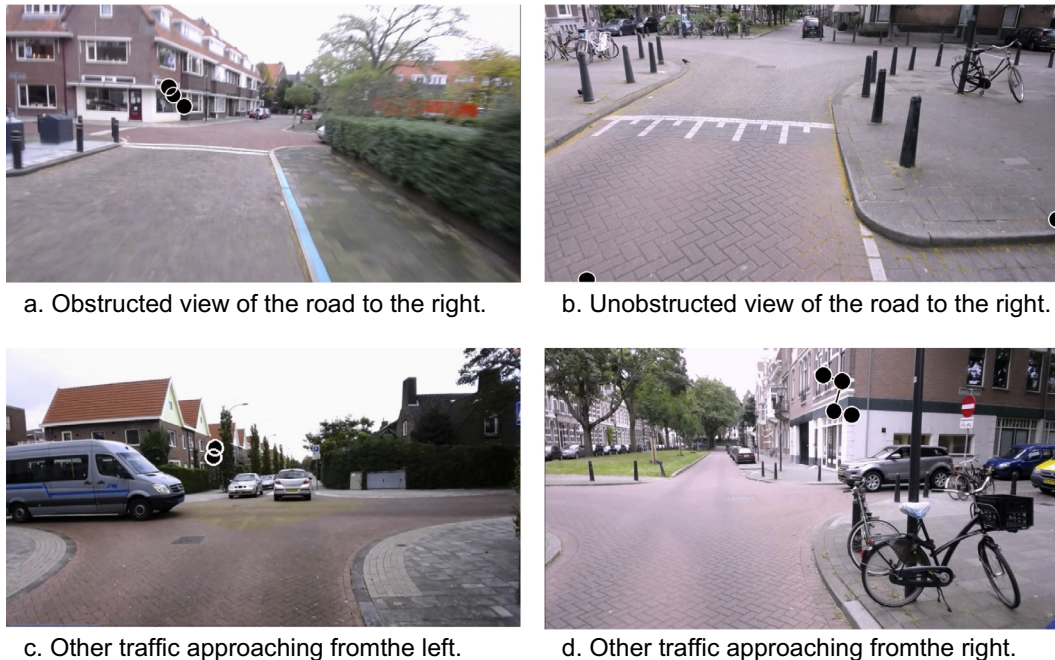


Fig. 2. Examples of uncontrolled intersection analysed in this study. The dots indicate the eye positions of the cyclist and the line connects the eye positions in temporal order.

These were mainly roads in residential districts and urban access roads. Most of them had not any dedicated cycle facilities (see Fig. 2 for examples). At 8% of all intersections other traffic was approaching from the right. This was often a passenger car (53% of all cases). At 4% of the intersections other traffic, often a cyclist (57% of all cases), was approaching from the left. Traffic densities at the intersections were rather low. Cyclists encountered especially pedestrians, motor vehicles and other cyclists. Only at 16% of all intersections the view of the road to the right was unobstructed.

4. Discussion

The current study compared the visual behaviour of teenage cyclists at uncontrolled intersections in two conditions: while listening to music and while 'just' cycling. To our knowledge this is the first study gathering semi-naturalistic data to investigate visual behaviour of teenage cyclists while listening to music. The aims of the study were: (1) to investigate whether cyclists listening to music increase their visual performance, (2) to present our study as a case study explicitly addressing ethical issues related to performing an on-road study and (3) to evaluate the data collection methodology applied in this study.

4.1. Main experiment: Effect of music on cyclists' visual behaviour

Our first aim was to investigate whether and to what extent cyclists change their visual behaviour while listening to music. Because listening to music impairs cyclists' auditory perception, cyclists may attempt to compensate for the decreased auditory input by increasing their visual performance. Our results showed that cyclists often failed to look to the right into the intersecting road, irrespective of whether or not they are listening to music. Although at the uncontrolled intersections cyclists were required to yield to the traffic coming from the right, only 45% of the intersections received cyclists' glances.

The finding that intersecting roads to the right often failed to capture cyclists' attention raises concerns. To illustrate, consider the following situation: a cyclist approaches an uncontrolled intersection and at the same time another road user approaches from the right on a collision course with the cyclist. It is crucial that the cyclist's attention is directed to the right. Attention selection may be driven by top-down expectations: even if the other road user is outside the cyclist's field of view, the cyclist may expect main hazards to come from the right based on his or her knowledge of and experience with uncontrolled intersections. If the cyclists' attention to the right is not captured in the top-down manner, visual features of the road user, e.g. movement, in the right field of view may still draw the cyclists' attention (bottom-up attention selection). In case of approaching 'non-silent' road users (e.g. conventional cars), their sound can additionally act as an attentional trigger facilitating their detection and localisation.

The question is, however, whether the bottom-up visual and/or auditory attention selection will provide cyclists enough time to react properly. An approaching road user may capture cyclists' attention too late because of visibility obstruction or cyclist's looking to the left or backwards. Recent studies using naturalistic cycling data show indeed that intersections with an obstructed view increase cyclists' risk of experiencing a critical event (Dozza & Werneke, 2014). Furthermore, with the increasing number of quieter, hybrid or electric vehicles on the road, the sound of the vehicle may not capture cyclists' attention early enough to afford a proper reaction (see Stelling-Konczak, Hagenzieker, & van Wee, 2015).

In the present study, cyclists' visual behaviour was not affected by listening to music. In the field experiment by Ahlstrom et al. (2016), similar results were found although the traffic environment in that study was less demanding than the one we focused on in our research. As already mentioned, cyclists in the study of Ahlstrom et al. were riding along a cycle track which had priority over the four intersecting side roads. In contrast, cyclists in our study were required to yield to the traffic coming from the right. The cyclists in both studies may have felt confident in traffic and felt no need to compensate for the limited auditory input. As shown, cyclists in our study reported that they could hear as much sound as they considered necessary to cycle safely. This finding is in line with recent research in which cyclists in cities where a cycling culture is established (such as cyclists in our study) reported feeling less fear of traffic, less frequent helmet use and being more often distracted than cyclists in emerging cycling cities (Chataway, Kaplan, Nielsen, & Prato, 2014).

The results of the present study should, however, be treated with caution due to the limited sample size. The relatively small sample size may have reduced the ability to detect small effects between the baseline and music conditions. Therefore, we realize that our study cannot provide strong evidence for the absence of visual compensation among cyclists who listen to music. However, if the absence of visual compensation reflects a true tendency, cyclists listening to music could be expected to be at more risk than cyclists who 'just' cycle. This because cyclists' attention may not be directed in a bottom-up manner towards a vehicle appearing in the periphery. Peripheral vision is normally very sensitive to contrast and motion and serves as an early warning system for moving targets entering the visual field (see e.g. Duchowski, 2003). Fundamental research shows, however, that visual attention is no longer captured by abrupt visual stimuli when a concurrent auditory task is present (Boot, Brockmole, & Simons, 2005). Additionally, as already mentioned in the introduction, the sound of an approaching vehicle may get masked by music and therefore fail to capture cyclists' attention.

It is also worth mentioning that although overall visual behaviour between the music and the baseline condition was not statistically different, there seemed to be three distinct groups of cyclists: those who decreased their visual performance while listening to music, those who increased their visual performance; and those whose visual behaviour was not affected

by listening to music. It will be valuable in future work to explore characteristics of these groups. The group who decreased their visual performance was the largest in our study – it consisted of 43–64% of the participants (depending on the performance measure). If the trend were to continue with a larger sample, a significant effect may be found in the ‘risky’ direction. Being aware of that possible effect of cyclists decreasing their visual attention while listening to music, we felt obligated to protect our teenage participants.

4.2. Ethical considerations

Our second aim was to present this study as a case study explicitly addressing ethical issues related to conducting a study in real traffic (see Section 2.1). To avoid exposing participants to potential risks related to cycling whilst listening to music, the cyclists in our study used their own bicycles and they were free to choose their own routes, travel and departure time. Furthermore, only those cyclists were included in our study who cycled regularly and who frequently listened to music while cycling. Finally, when the results indicated that a substantial percentage of participants cycling with music (43–64% depending on the visual performance measure; see also Table 3) decreased their visual performance, we decided to terminate the study. As a result, our sample was limited to fourteen cyclists, which might explain why listening to music did not significantly affect cyclists’ visual behaviour. It is, however, still possible that cyclists do change their visual behaviour when listening to music, but this change can only be detected with larger samples. An ethical dilemma arises: should people be exposed to potentially risky situations in the pursuit of significant results?

To date ethical considerations related to performing a study in real traffic have not been systematically and explicitly reported in transport and traffic safety journals. Furthermore, no clear international ethical standards appear to exist for traffic research. It is therefore unclear how various researchers in this field deal with the ethical issues related to protection of research participants. As shown in Section 1.1 not all traffic researchers are obliged to obtain an ethical approval (depending where the study is carried out) and even if a particular study has been approved by an ethical committee, it does not necessarily mean that another ethics committee would reach the same conclusions. Except for the reduction of risks for research participants, clear ethical standards ensure equal opportunities for traffic researchers at various universities and research institutes to conduct a ‘publishable’ study (see also Section 1.1).

We hope this study contributes to the discussion about the research ethics involved in road safety research and illustrates the dilemma related to conducting a study in real traffic. It is extremely challenging to investigate cyclists’ visual behaviour in ecologically valid conditions without inflicting potential dangers to participants. Can this dilemma be avoided by studying behaviour with the use of other research methods? From an ethical perspective, laboratory studies, providing a safe setting for participants, are preferable. There may be, however, some differences in how people distribute their visual attention in the natural environment compared to the laboratory setting. To illustrate, glance behaviour of pedestrians in the real world was found somewhat different than in the lab (Foulsham, Walker, & Kingstone, 2011). This is because cycling outdoors requires steering, pedalling and maintaining balance whilst monitoring the environment and the road quality (see for example Vansteenkiste, 2015). Furthermore, differences between laboratory and real-world settings can arise due to various sounds that are typically present in real traffic situations only, e.g. traffic sounds, wind noise, aerodynamic noise caused by the head of a cyclist moving through the air, people talking on the sidewalk or other loud masking noises. The reproduction of these real life cycling conditions in a laboratory setting is not an easy task. Only a few bicycle simulators in the world are high-fidelity immersive simulators offering realistic motion and visual experience as well as auditory information (see e.g. Plumert, Kearney, Cremer, Recker, et al., 2011; Scherfgen, Saitov, Zotos, Seele, et al., 2013). However, visual behaviour of cyclists in a bicycling simulator has not been validated yet against the behaviour of cyclists in real traffic (see e.g. Englund, Nilsson, & Voronov, 2016). It is also not known whether the simulation of the natural sounds provided by bicycle simulators is valid for the listener. Therefore, the relevance of bicycle simulators in studying cyclists’ visual behaviour needs yet to be established. It is also worth mentioning that validation research, although necessary to verify the usefulness of a bicycle simulator, requires data collection in real traffic, which again generates ethical issues.

Other available research methods, i.e. surveys and observational studies, have important disadvantages. Surveys rely on accuracy of memory and honesty of reporting and may reflect what people think they do, rather than their actual visual behaviour. Furthermore, this method cannot provide quantitative evidence on the location and duration of cyclists’ visual effort. Observational studies usually use hidden cameras. Observations are often conducted at a limited number of locations and for a limited period of time, which can limit the generalisability of results. Additionally, with this method cyclists’ visual attention can be determined only roughly, i.e. using head turns instead of eye movements. Finally, it is also not always easy to determine whether the observed cyclist is listening to music, e.g. earbuds may not always be visible.

4.3. Experimental set-up

The third aim of the present study was to evaluate to what extent the experimental set-up applied is suitable to examine bicyclists’ visual behaviour in situations crucial for their safety. We were especially interested in two aspects. The first aspect was the performance of the eye-tracker. The other aspect related to the question whether uncontrolled intersections, selected in this study as situations crucial for cycling safety, were demanding traffic situations for cyclists.

Results show that the use of an eye-tracker by cyclists who choose their routes and commuting time was feasible. Good quality eye-tracking data was gathered. The eye-tracking data was not disturbed by the sunlight although some of the trips

took place in sunny weather conditions. It is worth mentioning that we assumed, as in other eye-tracking studies, that eye-movements denote visual attention. The relationship between eye movements and visual attention is controversial and subject to common criticism as it is possible to dissociate attention from eye movements (see e.g. Engbert & Kliegl, 2003; Hagenzieker, 1992). Nevertheless, psychological evidence indicates that attention and eye movements are closely related (see e.g. Duchowski, 2003). We expect that in our study cyclists' eye movements denoted their visual attention, but we acknowledge awareness of the fact that it may not always be so. Furthermore, given the nature of eye-tracking technology measuring where a person's fovea² is directed, the present study has not taken into account the role of peripheral vision. This could be considered a limitation of this study. When at uncontrolled intersections, cyclists' fovea is not directed to the right, an approaching road user appearing in the right visual periphery can, due to its visual features, still capture cyclists' visual attention. However, relying on peripheral vision may not be a safe strategy to negotiate intersections: cyclists may have less time to react, obstructed view may unable cyclists to effectively use their peripheral vision and concurrent auditory task may inhibit cyclists' attentional capture (see also Section 4.1).

As already mentioned in the introduction, the semi-naturalistic approach chosen in this study gives researchers the opportunity to observe participants in a natural environment, but at the same time it does not allow for the control of traffic environment, e.g. traffic densities. Results of this study show that the traffic densities at the intersections were rather low. Only at 8% of all intersections other traffic was approaching from the right. Uncontrolled intersections, which were the focus of this study, although requiring cyclists to be alert for other traffic, especially for traffic approaching from the right, were probably, due to the low densities, not very demanding for cyclists. Cycling in heavy traffic, especially navigating through a roundabout or an intersection or crossing over, would obviously be more demanding. However, these traffic situations are often regulated by the Dutch cycling infrastructure, which is characterized by extensive and safe cycling facilities. Cyclists in the Netherlands still encounter complex situations; however, the presence and frequency of these situations could not be controlled while collecting (semi-) naturalistic data. Therefore, we may conclude that the methodology used in this study is less suitable to study glance behaviour of teenage cyclists in demanding traffic environment.

4.4. Conclusion

The popularity of listening to music among teenage cyclists has raised concerns about the impairment of auditory perception and its potential impact on cycling safety. Not being able to hear traffic sounds may decrease cyclists' awareness of approaching vehicles and lead to unsafe situations. The question is whether cyclists compensate for the decreased auditory input by increasing their visual attention. The current study addressed this question by collecting semi-naturalistic data. At the same time we explicitly addressed a number of ethical issues related to performing a study in real traffic.

Although this study found that listening to music does not significantly affect cyclists' visual behaviour, we cannot exclude that the effects do exist and can be found with a larger sample or in other, e.g. more demanding traffic environment. Future studies may wish to explore glance behaviour of (teenage) cyclists listening to music on a larger scale and in more demanding traffic situations. Semi-naturalistic data used in this study turned out to be less suitable to study glance behaviour of teenage cyclists in demanding traffic environment. Additionally, the methodology used in this study did not allow us to study cyclists' behaviour in a demanding traffic environment. At this moment, no other research methods seem suitable to address this research gap. Available methods have all disadvantages, either methodological or ethical.

This study showed fundamental ethical dilemmas involved in traffic safety research. We feel it is necessary that clear international ethical standards are developed and implemented within road safety research for a number of reasons. First of all, ethical standards are important to protect participants from risks. Next, ethical standards offer clear and equal opportunity for all researchers to conduct empirical studies and to have papers accepted for publication. Finally, ethical standards may stimulate the development of new research methods which will allow for gathering quantitative data in ecologically valid conditions without posing risks to participants.

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² The fovea is a small part of the eye responsible for our sharp, colourful vision.

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