Cyclists and traffic sounds: the results of an internet survey

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ABSTRACT

Many cyclists, especially youngsters, listen to music and talk on their mobile phones while cycling. As a result, auditory traffic information that can be used by cyclists to make safe decisions is less available. Also the growing number of quiet (electric) vehicles on the road makes use of auditory cues more challenging for cyclists. Although concerns have often been raised both about the impact of listening to music or having a phone conversation when on the road and about the impact of low sound emission of electric cars, the role of auditory information in cycling safety has not been systematically investigated yet. The present study examined to what extent and in which traffic situations, traffic sounds are important for safe cycling. Furthermore, the study investigated potential safety implications of limited auditory information caused by listening to music and talking on the phone while cycling and by quiet cars. An internet survey among 2250 cyclists in three age groups (16-18, 30-40 and 65-70 year old) was carried out to collect information on the following aspects: 1) frequency of listening to music and talking on a mobile phone while cycling and devices used to engage in these activities 2) cyclists' encounters with quiet vehicles 3) possible contributions of quiet vehicles, listening to music and phoning while cycling to self-reported bicycle crashes, while taking into account other potentially relevant factors such as demanding traffic situation, personality and risky cycling behaviour and 4) possible compensatory behaviours of cyclists who listen to music or talk on their mobile phones. Age differences in those four aspects have been analysed. Results of the study and its implications are discussed.

Keywords: cycling safety, music, mobile phone, auditory perception, electric vehicles.

1 INTRODUCTION

Cycling injury represents one of major traffic safety issues. EU-wide developments show that cyclists benefit less from overall safety improvements that are reducing overall crash rate (Steriu, 2012). Countries where exposure data is collected may show a decrease in crash risk between 2001 and 2009, however, the decrease is either very slight (Norway), it stagnates (the Netherlands) or the decreased fatality risk is still relatively high (Great Britain) (OECD/International Transport Forum, 2013; Steriu, 2012). Only in Denmark the crash risk has deceased significantly to a low level of 8.5 per billion kilometres ridden. Moreover, the risk of serious injury among cyclists is actually showing an increasing trend over the period 2000–

2009 in the Netherlands. Data on non-fatal bicycle crashes in other countries is generally scarce and more subject to under-reporting than data on cyclist fatalities (OECD/International Transport Forum, 2013). Given these negative trends and the efforts of many countries to encourage cycling, it is important to identify and address factors that negatively influence cycling safety. One of such factors may be limited availability of auditory cues from traffic environment.

Visual information is crucial to navigate through the traffic environment. However, for cyclists auditory cues such as pavement, tire and engine noises can be of great importance especially when detecting and localizing traffic from areas outside cyclists' visual field-of-view. According to the model of Stelling-Konczak, Hagenzieker & Wee (Stelling-Konczak, Hagenzieker & van Wee, 2013; Stelling-Konczak, Hagenzieker & van Wee, submitted) inaccurate detection and localisation of approaching traffic sounds can negatively affect cyclists' decision making, cycling performance and eventually cycling safety. Recently two trends have raised concerns about the availability of auditory information for cyclists. One is the proliferation of electronic mobile devices/cell phones and other portable technologies that are often used when on the road. Many cyclists, especially youngsters listen to music and talk on the phone. In the Netherlands 41% of the cyclists listen to music and 58% engage in a phone call at least occasionally (Goldenbeld, Houtenbos & Ehlers, 2010; Goldenbeld et al., 2012). Speech and music may reduce or completely eliminate auditory cues from the traffic environment leading in the end to unsafe situations. The second trend regards the increasing number of electric cars, which are generally quieter than conventional cars when driven at low speeds. Global sales of electric vehicles more than doubled between 2011 and 2012 (IEA, 2013). The number of electric cars will presumably increase profoundly in the near future as many European countries want to stimulate the use of electric cars. The Netherlands, for example, aims to have 200,000 electrically powered cars in 2020 and one million in 2025 (IEA, 2012). In January 2013, there were more than 90,000 fully electric and hybrid cars (of all types) in the Netherlands, which constitute 1.1% of the total number of Dutch cars.

1.1 Safety implications of listening to music and talking on the phone

Little is known about the extent to which listening to music or talking on the phone while cycling compromises auditory perception of cyclists. A Dutch field experiment found that about 5-20%[1] of cyclists listening to music and about 25% of cyclists talking on the phone heard all presented sounds of a bicycle bell as compared to about 70% of cyclists who were not using devices (De Waard, Edlinger & Brookhuis, 2011). Furthermore, high tempo or loud music and in particular music listened through in-earbuds impaired the perception of a loud sound i.e. horn honking. Not hearing a relevant traffic sound can pose a safety hazard especially when cyclists do not compensate for the reduction of auditory cues by, for example, by increasing visual attention or decreasing cycle speed. Experimental studies show minor behavioural compensation of cyclists listening to music or talking on the phone (De Waard, Edlinger & Brookhuis, 2011; De Waard et al., 2010). Phoning was associated with cycle speed reduction (especially when performing a difficult phone task), but listening to music was not. As regards visual attention, no increase in the number of detected visual objects among cyclists who are using portable electronic devices was found. What is more, two of these studies show a deterioration of visual detection among cyclists who were having a phone conversation (especially a difficult one) as compared to non-phoning cyclists (De Waard et al., 2010). Other types of behavioural compensation for listening to music or talking on the phone have not been experimentally studied.

Research into safety implications of limited availability of auditory information caused by listening to music or talking on the phone while cycling is scarce. Few studies investigated the contribution of the use of devices while cycling to crashes. A Japanese survey among students (aged 15-18 years old) indicates a possible risk-increasing effect of the use of mobile phones

[1] Depending on the type of music and the manner of listening

while cycling (Ichikawa & Nakahara, 2008). Furthermore, two Dutch surveys among cyclists suggest that listening to music while cycling may have contributed nationally to 3-5% of self-reported injury crashes. Engaging in other secondary activities while cycling (i.e. having a phone conversation, but also texting or searching for information) may have caused an additional 3-4% of self-reported injury crashes (De Waard et al., 2010; Goldenbeld, Houtenbos & Ehlers, 2010). The study of Goldenbeld et al. provides also a more accurate indicator for the impact of the use of devices on road safety levels by calculating the crash risk (Goldenbeld et al., 2012). After having corrected for various potentially relevant exposure factors (such as the extent to which cyclist were exposed to hazardous traffic situations), the risk of a self-reported crash for cyclists, who used electronic devices on every trip, turned out to be a factor 1.6 higher for teen cyclists and 1.8 higher for young adult cyclists compared with their respective age counterparts who never used devices while cycling. For cyclists aged 35-65, however, no increase in crash risk was found. Unfortunately, those studies, as well as international literature analysing crashes involving cyclists, do not provide sufficiently detailed information to figure out to what extent the crashes involving cyclists using devices can be associated with the compromised auditory perception. There may be some other aspects related to the use of devices which make them potentially dangerous, such as visual distraction (especially when texting), cognitive distraction (especially when talking on the phone) or effect on emotions or mood states (especially music). Furthermore, some characteristics of cyclists who use devices (e.g., psychological determinants such as sensation seeking; cf. Zuckerman, 2002) as opposed to those who 'just cycle' might be related to the increased crash risk of the former regardless of limited availability of auditory information. For example, if cyclists who listen to music or talk on the phone are also more often involved in other types of risky cycling behaviour (e.g. violating a red traffic light) than cyclists who 'just cycle', it is difficult to determine whether the increased crash risk should be ascribed only to (the degraded auditory perception resulting from) the use of devices or to a combination of both listening to music or talking on the phone and those risky behaviours. Similarly, the characteristics of traffic environment are likely to influence the impact of the use of devices while cycling. For example, if cyclists using devices cycle more often in complex situations than cyclists not using devices, it is difficult to determine whether the increased crash risk should be ascribed only to the degraded auditory perception resulting from the use of devices or to a combination of both the use of devices and the complex traffic situation.

1.2 Safety implications of electric cars

Research shows that, in comparison with conventional cars, hybrid electric cars are generally quieter and more difficult to detect by (visually impaired) pedestrians when they are driven at low speeds (generally up to 15 km/h) and in environments with low ambient noise. To our knowledge, no such studies have been performed among cyclists. It can, however be expected that similar differences in detection between electric and conventional cars also apply for cyclists. A recent laboratory study including vehicle motion paths relevant for cycling activity found that electric cars driven at low speeds were localise less accurately than conventional cars (Stelling-Konczak et al., submitted). Studies among drivers of electric vehicles suggest that pedestrians and cyclists have problems hearing electric cars when those cars are driven at low speeds (Cocron et al., 2011; Hoogeveen, 2010). No crashes caused by the low sound emission of electric vehicles were reported by the drivers participating in the studies, but there were some noise-related incidents (Cocron et al., 2011; Hoogeveen, 2010) and startling reactions among vulnerable road users (Hoogeveen, 2010), especially at low speeds. As far as objective measures of estimating potential danger caused by electric cars are concerned, the crash risk of those cars cannot be calculated and compared to the risk of conventional cars as exposure data (i.e. kilometres travelled by conventional and electric cars) are unavailable.

1.3 This paper

Given the popularity of electronic devices among cyclists and the ambition of many countries to increase the share of electric vehicles, more and more cyclists who listen to music or talk on the phone will encounter electric cars. It is therefore important to investigate separate as well as combined effects of both trends for cycling safety.

The aim of this paper is twofold. One is to investigate the impact of listening to music and talking on the phone and resulting deteriorated auditory perception on cycling safety. Using a hypothetical model we controlled for the potential influence of other risk factors (see the next section). The other aim is to analyse the experiences with quiet (electric) cars of cyclists in general and particularly cyclists who are listen to music or talk on the phone when cycling.

Three age groups have been used in the present study. Age is an important factor from the perspective of cycling safety. In the Netherlands, for example, many fatalities among cyclists involve teenagers (particularly 16-18 year olds) and the elderly (Kline, 1999). Younger cyclists are involved in other type of crashes than adults and the elderly; the elderly are often involved in bicycle-only crashes (not involving impact with another road user), while teenage cyclists often crash with a motor vehicle (generally resulting in serious consequences). Furthermore, compared to other age groups, young cyclists are more often engaged in activities that can limit the availability of auditory traffic information such as listening to music or talking on the phone. Young road users may be more vulnerable to distractions because they may lack the ability to anticipate and manage hazards (Vlakveld, 2011). Young road users can also be characterized by mental and physical immaturity, a high risk acceptance and an overestimation of their own skills. Their exposure to dangerous situations is often high (the young, especially males, more often drive at night and during the weekend) (e.g. Vlakveld, 2011). Last but not least, hearing deteriorates with age, which can have implications for the use of auditory information by older cyclists (e.g. Van Eyken, Van Camp & Van Laer, 2007) .

1.4 Hypothetical model

In assessing the contribution of listening to music and talking on the phone to cycling crashes, we attempted to control for the influence of other potential risk factors i.e. cyclist's psychological determinants of risk behaviour, various risk behaviour types and characteristics of traffic environment. Through a review of the literature into personality, social and cognitive determinants of risky behaviour in traffic (with a special focus on non-driving road users) a number of cyclist's risk determinants and risk behaviour types were identified (see Table 1).

As far as risk behaviour types are concerned, the terms 'errors' (unintentional deviations from safe practices that reflect inadequate skills) and 'violations' (deliberate deviations from normal safe practice or socially accepted code of behaviour) originate from Reason et al.'s (1990) theoretical framework. Reason et al. initially developed the Driver Behaviour Questionnaire (DBQ), widely used to study risky driving behaviour among adult drivers. The studies presented in Table 1 among non-motorized road users used modified versions of DBQ, as pedestrian or cyclist behaviour is quite different from car driving behaviour. Extra types of risky behaviour were also added, for example 'Lack of protective behaviour' (lack of behaviours deriving their effectiveness not from skilled interaction with traffic but from isolating the respondent from some form of risk, Elliott & Baughan, 2004). Furthermore studies among adolescents include often 'Dangerous play' (deliberate participation in behaviour involving ''playing with traffic", Elliot, 2004), risky behaviours specific to this age group. Based on the results of the studies presented in Table 1, we have identified three types of risky behaviours as suitable to examine cyclists of various age groups in this study: errors, violations and lack of protective behaviour.

Table 1. Psychological determinants of risky behaviour (*) and risky behaviour types related to crashes (**) among non-motorized road users.

Study	Road user	Age group	Significant factors
Elliott & Baughan (2004) United Kingdom	Pedestrians and cyclists	11-12 13-14 15-16	Dangerous play** Lack of protective behaviour** Unsafe crossing**
Feenstra et al. (2011) Netherlands	Cyclists	13-18	Errors** Violations** Extreme violations **
Sullman & Mann (2009) New Zealand	Pedestrians and cyclists	13-18	Dangerous play** Lack of protective behaviour** Unsafe crossing**
Twisk et al. (submitted) Netherlands	Pedestrians and cyclists	12-13 & 14-16	Errors ** Lack of protective behavior ** Dangerous play **
		12-13	Knowledge about traffic rules* Carelessness* Opinions about social behaviour*
		14-16	Hazard awareness* Opinions about alcohol* Competence in comparison to others* Feeling responsible for one's actions*
Yao & Wu (2012) China	E-bike riders	18-30 30-50 >50	Errors** Aggressive behaviour** Attitudes towards safety & responsibility* Risk perception*

Little is known about psychological determinants of risky cycling behaviour. As only two studies investigating this subject were found, relevant research among car drivers was also reviewed. Risky driving behaviour has often been associated with risk perception (Rundmo & Iversen, 2004; Ulleberg & Rundmo, 2003)and a number of personality traits (sensation-seeking, impulsiveness, anger and aggression, see e.g. Beanland, Sellbom & Johnson, 2014).

Given the length of the questionnaire and the time commitment required to complete it, we decided to use two psychological determinants in the present study: risk perception and sensation seeking. Finally, two other relevant risk factors (significant predictors of crash involvement among cyclist, Goldenbeld et al., 2012) were identified: time spent cycling and exposure to complex traffic situations (i.e. cycling in darkness, etc.).

To sum up, in assessing the impact of listening to music and talking on the phone on cycling safety, we attempted to control for the influence of the potential risk factors: risk behaviour (errors, violations and lack of protective behaviour), psychological determinants of risk behaviour (risk perception and sensation seeking) and exposure-related risk factors (time spent cycling and exposure to risky traffic situations). To this end the following hypothetical model was developed (see Figure 1). We hypothesized that cyclist characteristics (i.e. sensation seeking and risk perception), cycling exposure in general and exposure to complex traffic situations could influence risk behaviours including listening to music and talking on the phone. Risk behaviours in turn were expected to affect frequency of incidents (see e.g. Kinnear et al., 2013) and eventually crash frequency.

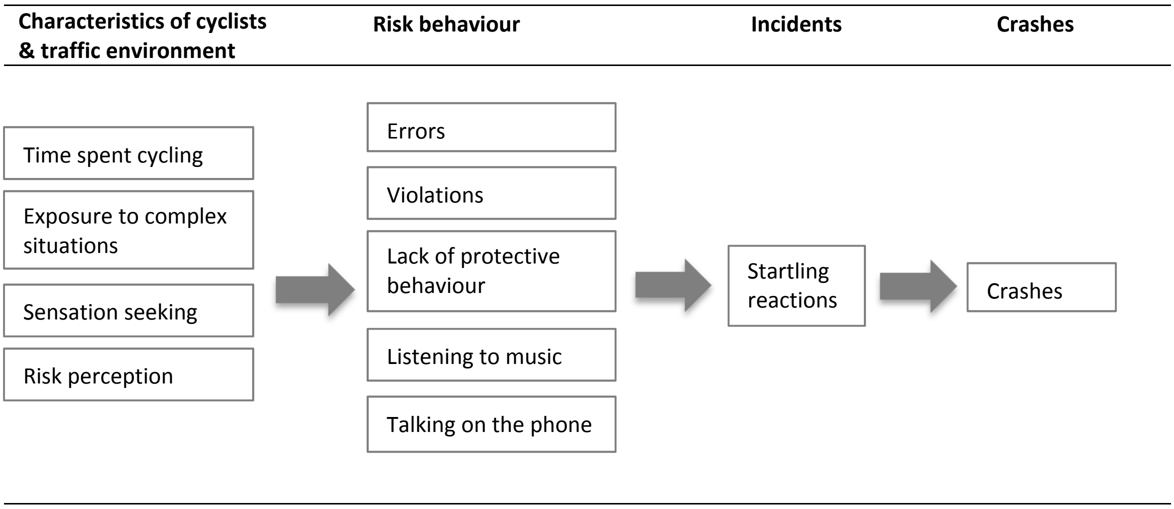

Figure 1. Hypothetical model of the study.

2 METHODS

2.1 Survey sampling and administration

An online methodology was considered well-suited in obtaining a representative sample of Dutch cyclists since more than 80% of Dutch inhabitants own a bicycle (CROW Fietsberaad, 2014) and 92% of Dutch households are connected to the internet (European Commission, 2013). The survey was administered on-line between 13 and 30 June, 2014 via a survey company that maintains an online panel. Data was collected from 2250 respondents in three age groups: young: 16-18 yrs (n=748; 50% female), middle-aged: 30-40 yrs (n=749, 50% female) and older: 65-70 yrs (n=752, 50% female). Respondents recruited had to cycle at least once a week and report no major hearing deficiencies. The sample was representative of the national Dutch population in terms of educational level and regional distribution. It took about 20 minutes to complete the survey.

2.2 Questionnaire

The survey contained the following parts: demographics, exposure and bicycle use, use of electronic devices, traffic sounds, behavioural prevention and compensatory behaviour regarding the use of electronic devices in traffic, crashes, psychological determinants and risk behaviour

2.2.1 Demographics

Respondents were asked about their gender, age, hearing abilities and the type of school they have attended or are still attending.

2.2.2 Exposure and bicycle use

Exposure was measured by two variables: average number of trips during an ordinary week and the usual time spent cycling during a trip. A composite scale 'bicycle use in demanding situations' was used to measure the frequency of cycling in demanding traffic situations: in darkness, frequent intersections, roundabouts or crossings of the road, heavy traffic, sharing the road with motor vehicles, heavy bus/truck traffic, heavy (light-)moped traffic (answer scale 0 =never; 1 =seldom; 2 =on some bicycle trips; 3 =on most bicycle trips, 4 =all bicycle trips). Furthermore, respondents were asked about their helmet use, the type of bicycle they usually use and whether they cycle on their own or accompanied by others.

2.2.3 Use of electronic devices

Respondents were asked about the frequency of listening to music, talking on the phone, texting and searching for information on the phone (e.g. about the weather, route or accessing social networking sites) while cycling. Questions about texting and searching for information were asked to place the frequency of listening to music and talking on the phone in the perspective of other activities which electronic devices (smartphone) offer. For each type of device use, respondents had to indicate how frequently they use it during an ordinary cycling week (answer scale: 0 =never; 1 =seldom; 2 =on some bicycle trips; 3 =on most bicycle trips, 4 =all bicycle trips) and how frequently they use it while cycling in more demanding traffic situations mentioned in 2.2.2. Furthermore respondents had to indicate the manner of listening to music and talking on the phone (e.g. using a headphone, using earbuds, loudspeaker, etc.).

2.2.4 Traffic sounds

Respondents were asked to indicate how much they can hear when listening to music and talking on the phone while cycling and how much a cyclist should hear to be able to cycle safely (response options: 0=nothing at all, 1=not much, 2=only loud or sharp sounds, 3=most sounds, 4=all sounds, 5=don't know). Additionally respondents were asked whether they had been startled or surprised by some other road user in the past month, and if so to give some more details about (the most recent) case (such as the reason of startling, the type of road user involved and whether the respondents were listening to music or talking on the phone at that time). Furthermore, two questions were asked about quiet, electric cars: hoe often the respondents encounter a quiet (electric) car when cycling (response options: 0 =never; 1 =seldom; 2 =on some bicycle trips; 3 =on most bicycle trips, 4 =all bicycle trips, 5=don't know) and whether they know how an electric car sounds like.

2.2.5 Compensatory behaviour

Compensatory behaviour was measured by asking cyclists what they usually do when they get called or want to call someone when cycling. Respondents were also asked whether they adapted their cycling behaviour when listening to music and talking on the phone and if so to specify type of behaviour (e.g. turning the volume down, choosing other routes, being more alert, biking more slowly). Furthermore respondents were asked to indicate whether there were some specific traffic conditions in which they decided not to listen to music or to talk on the phone and if so to specify these conditions (e.g. heavy traffic, bad weather, feeling sick, etc.).

2.2.6 Crashes

Crash involvement was measured using two items: a binary item on crash involvement in the past 12 months (yes/no) and an item on the number of crashes (if 'no' was chosen the number of crashes was set to 0). Respondents who reported being involved in one of more crashes were asked further questions about the crash (in case of several crashes the most recent one): which type of bicycle they were cycling at that time, and which circumstances had preceded or accompanied the crash (such as 'I was just cycling'; 'Visibility was poor'; 'There was much environmental noise'; 'The road user involved in the crash was very quiet so I did not hear them coming'; 'I was talking on the phone'; 'I was listening to music'; 'I was talking to my fellow cyclist'; 'I was texting'; 'I was busy with/distracted by something', etc).

2.2.7 Psychological determinants

Sensation seeking (i.e. the need for excitement and stimulation) was measured with Impulsive Unsocialized Sensation Seeking (ImpSS) scale (which consists of 19 forced-choice items: true or false) (Zuckerman, 2002) (in Dutch) involving items on a lack of planning, the tendency to act impulsively without thinking, experience seeking and the willingness to take risks for the sake of excitement or novel experience (Zuckerman, 1993). The Dutch version of the Sensation Seeking scale has been validated by e.g. Feij et al. (1997). The percentage of true scores out of the total number items was used for the analysis. A high score on the scale indicated a high level of sensation seeking.

Risk perception was measured by 4 items (Rundmo & Iversen, 2004) regarding worry and insecurity about cycling-related injury and risk for the respondent himself or herself as well as for other cyclists (e.g. 'I feel unsafe that I could be injured in a bicycle accident'; 'I am worried for others being injured in a bicycle accident'). The worry and insecurity subscale was chosen since its relationship with risky traffic behaviour has been found to be stronger than the cognition-based risk perception (Rundmo & Iversen, 2004). Response options ranged from 1 = *does not apply to me at all* (low risk perception) to 6 = *strongly applies to me* (high risk perception). A mean score was constructed on the basis of the four items.

2.2.8 Risk behaviour

Three types of risk behaviours were included in the survey: violations, errors and lack of protective behaviour. Most of the items were selected from a modified Adolescent Road Behaviour Questionnaire developed by Twisk et al. (under review) to study pedestrian and cyclist behaviour. Some items concerning pedestrian behaviour were replaced by items on cycling behaviour. Adolescent-specific items (e.g. 'As a cyclist having yourself pulled by a moped rider') were replaced by age and sex-neutral items. Each type of risk behaviour consisted of 8 items (24 items totally). Responses to the items consisted of six-point Likert scales (with categories ranging from 'never' = 1 to 'always' = 6).

2.3 Analysis

The reliability and internal consistency of risk perception, sensation seeking, risk behaviour and demanding cycling situation scales were assessed using Cronbach's alpha. Values equal to or exceeding .70 were considered internally consistent (Kline, 1999).

To investigate whether the answers to the risk behaviour questions underlie the three types of risk behaviour (Errors, Violations and Lack of protective behaviour) a categorical principal component analysis (CATPCA) was performed. 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. With this technique, a spatial image in a two-dimensional space can be obtained, where objects (i.e. respondents) are represented by points, and items as vectors (Gifi, 1990). The closer points are located to one another, the more similar are the answer patterns of the respondents concerned. The more vectors are pointing in the same direction, the stronger the relationships are between the items they represent. Using the position of points with respect to a certain vector, CATPCA can moreover assign values to the scores of the respondents, or object scores, based on the components solution.

One-way ANOVA or a chi-square test (for nominal measures) was used to test for differences between age groups.

Path analysis in AMOS (22.0) for SPSS was performed to investigate the linear relationships between the variables shown in Figure 1. Path analysis allows an observed variable to be simultaneously treated as independent (exogenous) and dependent (endogenous) variable. Specifically, in this this study, a path analysis allows to investigate the influence of listening to music and talking on the phone on cycling safety (startle reactions), while controlling for cyclists' characteristics, time spent cycling and characteristics of the traffic environment as important background variables. For each age group, the hypothetical path model was tested and a final model was developed using a cross-validation strategy. The dataset was randomly split into two subsets: a calibration sample and a validation sample. The calibration sample was used to test the hypothetical model as well as to conduct post-hoc analyses to attain the best-fitting model. The best model was obtained by first removing all statistically non-significant parameters, followed by iteratively freeing parameters as indicated by the modification indices, in order from largest to smallest index value, and thus continuing until further modifications only marginally improved the model fit. Once the final model was determined, its validity was then tested based on the validation sample. Maximum likelihood estimation was used. Various fit indices were used to assess the fit of the model: chi-square, the goodness-of-fit index (GFI), the adjusted goodness-of-fit index (AGFI), the root mean square error of approximation (RMSEA). Conventional cut-off values that indicate a good model fit (RMSEA < 0.09, GFI and AGFI > 0.90) were used to guide model evaluation and selection (see e.g. Byrne, 2010; Hu & Bentler, 1995). Furthermore, a non-significant chi-square, had to be obtained. The chi-square test measures the discrepancy between a hypothesised model and the data (Bagozzi & Heatherton, 1994). Significant values of the chi-square test indicate a strong divergence between the data and the model.

3 RESULTS

3.1 Reliability and internal consistency of measures

Categorical principal component analysis was performed in order to investigate whether the answers to the risk behaviour questions underlie the three types of risk behaviour (Errors, Violations and Lack of protective behaviour). High scores on all the items indicated non-risky behaviour. Four items were recoded to conform with this direction of coding. The analysis revealed two factors (decided upon by an eigenvalue > 1) which accounted for 55.1% of the variance (the first factor accounted for 49.6% and the second one for 5.5%). The component loading ranged from .58 to .81 for the first component and from .45 to .58 for the second component. The items loading on the second component were the four recoded items only (one 'error'-item and three 'lack of protective behaviour'-items) suggesting that the respondents responded to the different way of phrasing the items. Those items were removed from further analysis increasing internal consistency of the scale (from Cronbach's α = .88 to .94). Based on Kline's criterion (Kline, 1999) of a Cronbach's α larger than .70, all subscales can be considered internally consistent. A new categorical principal component analysis of 20 items revealed two components with eigenvalue greater than 1.0. (10.3 and 1.22 respectively). The first component accounted for 51.7% of the variance and the second one for 6.1% of the variance. All items loaded higher on the first component (component loadings ranged from .59 to 81), suggesting that a single component best described the data (see Table 2). Object scores calculated (on Dimension 1) were used for further analysis.

Table 2. Component loadings

	Dimension	
	1	2
RB 1	,802	-,186
RB 2	,699	,325
RB 3	,719	,380
RB 4	,810	-,011
RB 6	,745	,112
RB 8	,662	-,273
RB 9	,794	-,189
RB 10	,734	-,118
RB 12	,659	,343
RB 13	,731	-,291
RB 14	,804	-,215
RB 15	,748	-,345
RB 16	,589	,364
RB 17	,790	-,092
RB 18	,807	-,207
RB 19	,582	,101
RB 20	,637	,392
RB 22	,660	,123
RB 23	,649	-,154
RB 24	,689	,212

Variable Principal Normalization

3.2 Exposure and bicycle use

Teenagers spent more time cycling (*M*=262 minutes a week) than the middle-aged (*M*=179 minutes a week) and older respondents (*M*=240 minutes a week): $F(2, 2248)$=8.25; p<.001.

The majority of respondents reported good hearing (16-18 yrs: 89.2%; 30-40 yrs: 84.6%; 65-70 yrs: 66.0%). Teenagers and middle-aged respondents cycled more often in demanding situations (respectively: *M*=3.35, *SD*=.70 and *M*=3.30, *SD*=.75) than the older cyclists (*M*=2.92, *SD*=.76): $F(2,2248)$=77.20, p= .000, significant post-hoc tests). Most respondents (84.5%) usually cycled on a conventional bicycle (ladies' bike or men's bike). However, much more respondents (20%) in the oldest group usually cycle on an e-bike than the other age groups (16-18 yrs: 2.7% and 30-40 yrs: 0.5%). The majority of the respondents cycled alone or more often alone than accompanied.

3.3 Use of electronic devices

The frequency of electronic device use while cycling differed between age groups. Teenage respondents were the most frequent users of electronic devices and the oldest respondents rarely used electronic devices (see Table 3). Listening to music or radio was reported by 77% of teenage respondents, 43% of the middle-aged respondents and by only 6.2% of the oldest respondents. Almost a quarter of the teenage cyclists reported listening to music or radio during each trip (versus 6.3 of middle-aged and 0.4 of older cyclists). Listening to music or radio was the most frequent device use among the teenagers. Texting and information search were less frequent, and making a phone call was the least popular device use among the teenagers. Approximately the same percentage of the middle-aged respondents (40-45%) reported listening to music, made a phone call or texted while cycling, while searching for information was less popular (about one-third). In comparison with listening to music, the middle-aged cyclists engage in making a phone call, texting or searching for information engage rather infrequently (seldom or on some trips).

As far as the older cyclists are concerned, only 6 to 10% of them reported using devices while cycling: 6.2% reported listening to music, 10.1% making a phone call, 9.2% reading a text message, 6.6% typing a text message and 10.2% searching information. The older adults who use devices, use them only seldom.

The age differences concerning the frequency of listening to music, making a phone call, answering the phone, reading and typing text messages were significant (respectively: $\chi 2=847.4$; df=8; $p<.001$; $\chi 2=459.8$; df=8; $p<.001$, $\chi 2=409.8$; df=8; $p<.001$; $\chi 2=748.7$; df=8; $p<.001$ and $\chi 2=734.3$; df=8; $p<.001$).

Table 3. Frequency of electronic device use per age group; the Table shows usage percentages of the various devices listed in the columns, for each age group.

		Listening to music	Making a phone call	Texting: reading/typing	Infomation search
16-18 yrs	never	23.0	37.3	26.7/ 29.4	41.3
	seldom	14.2	36.8	21.4/ 21.8	28.9
	on some trips	19.5	20.6	29.3/ 27.4	18.2
	on most trips	19.1	2.9	14.4/ 13.9	7.5
	on all trips	24.2	2.4	8.2/ 7.5	4.1
30-40 yrs	never	57.5	57.0	55.3/ 59.8	68.1
	seldom	14.8	26.2	24.8/ 22.7	18.6
	on some trips	11.5	11.9	14.6/ 12.0	9.2
	on most trips	9.9	2.7	3.1/ 3.5	2.0
	on all trips	6.3	2.3	2.3/ 2.0	2.1
65-70 yrs	never	93.8	89.9	90.8/ 93.4	89.8
	seldom	4.3	8.6	7.2/ 5.3	7.6
	on some trips	1.3	1.2	1.5/ 0.9	2.1
	on most trips	0.3	0.1	0.1/ 0.1	0.3
	on all trips	0.4	0.1	0.4/ 0.3	0.3

The most popular manner of listening to music in each age group was using earbuds (reported by about 40% of the respondents) followed by using one earbud (chosen by 21-23% of the respondents) (Figure 2). Manner of listening to music differed between age groups ($\chi 2=35.15$; $df=12$; $p<.001$). For example, using in-earbuds was reported by about 16% of the teenage and the middle-aged cyclists but by none of the older cyclists.

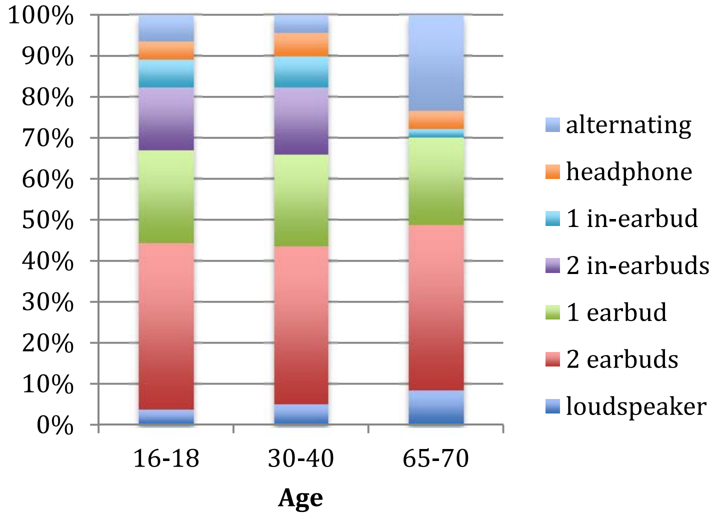

Figure 2. Manner of listening to music

There were also differences between age groups concerning the frequency of listening to music while cycling in demanding situations (*F(2,940)*=15.28, *p*= .00). The older cyclists refrained most often (*M*=2.62, *SD*=.98) and the teenage cyclists (*M*=1.91, *SD*=.98) the least often from listening to music while cycling in demanding situations (middle=aged cyclists: *M*=2.16, *SD*=1.03). All post-hoc tests were significant.

3.4 Traffic sounds

A great majority of the respondents (about 90% in each age group) indicated that a cyclist should hear all or most sounds in order to cycle safely. Being able to hear all sounds was more often reported by the older cyclists (63%) than by the teenage (47%) or the middle-aged respondents (57%). Only 1% of the respondents in each age group indicated that a cyclist does not have to hear anything at all in order to be able to cycle safely. The age differences found were significant: ($\chi2$=47.0; *df*=8; *p*<.001).

Figure 3a shows that 66%-81% of the respondents report being able to hear all or most sounds while listening to music. The higher percentage corresponds to the oldest group, and the lower percentage to the middle-aged cyclists. As far as auditory perception while talking on the phone is concerned, about three-quarter of the respondents in the two younger groups and two-thirds in the oldest group claim they can hear all or most sounds. Especially the teenagers reported being able to hear all sounds, while more the middle-aged respondents than the teenagers and the older cyclists indicated that they can hear most sounds when talking on the phone. The age differences found were significant: ($\chi2$=42.0; *df*=10; *p*<.001).

When comparing Figures 3a with 3b and 3c, we can see a cyclist should hear more than what can be heard by the cyclists who listen to music or talk on the phone when cycling. Furthermore, when comparing the cyclists who listen to music and/or talk on the phone with those who never engage in those activities, we can see that a higher percentage of the latter group indicated that cyclists should hear all sounds in order to cycle safely ($\chi2$=78.6; *df*=4; *p*<.001) (Figure 3d).

As far as auditory perception while talking on the phone is concerned, about three-quarter of the respondents in the two younger groups and two-thirds in the oldest group claim they can hear all or most sounds. Especially the teenagers reported being able to hear all sounds, while more the middle-aged respondents than the teenagers and the older cyclists indicated that they can hear most sounds when talking on the phone. The age differences found were signifi cant: ($\chi2$=42.0; df=10; p<.001).

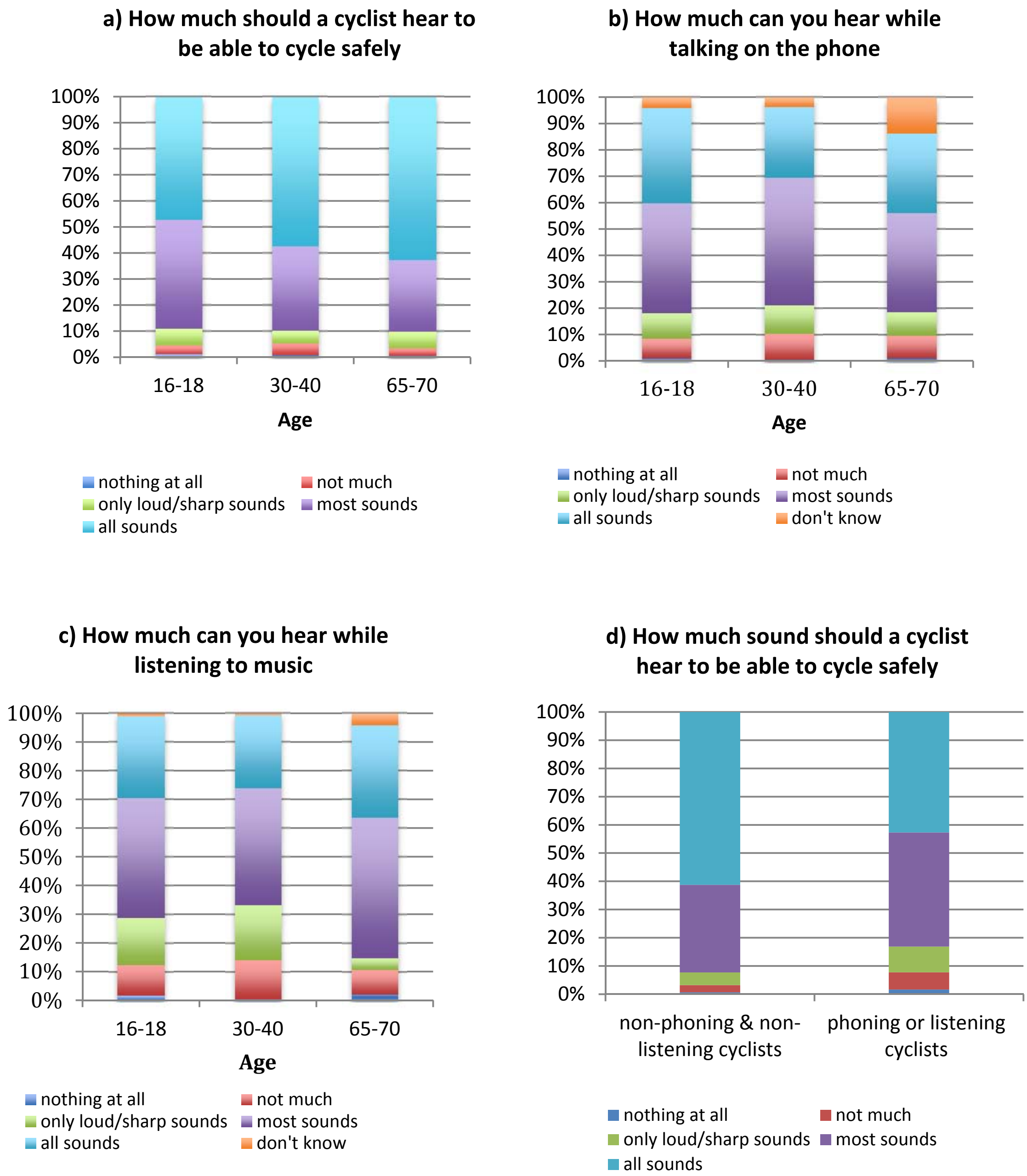

Figure 3. The extent to which cyclists: should hear traffic sounds to be able to cycle safely per age group (a) and per type of cyclist (phoning/listening to music versus non-phoning/listening to music) (d) can hear sounds when talking on the phone (b) and listening to music (c) per age group.

Significant differences were found also between age groups with regard to the frequency of being startled/surprised by some other road user in the past month ($\chi2$=54.1; df=6; p<.001) (Figure 4a). More than half of the respondents in each group had never been startled or surprised in the past month (52% of teenage, 58% of the middle-aged and 56% of the older cyclists). A higher percentage of the older respondents was startled/surprised ‘more than once’ as compared to the teenage and middle-aged respondents.

The teenage and middle-aged respondents were especially startled/ surprised by car drivers. The older respondents were also often startled/surprised by cyclists and (light) moped riders ($\chi2$=70.2; *df*=10; *p*<.001) (Figure 4c).

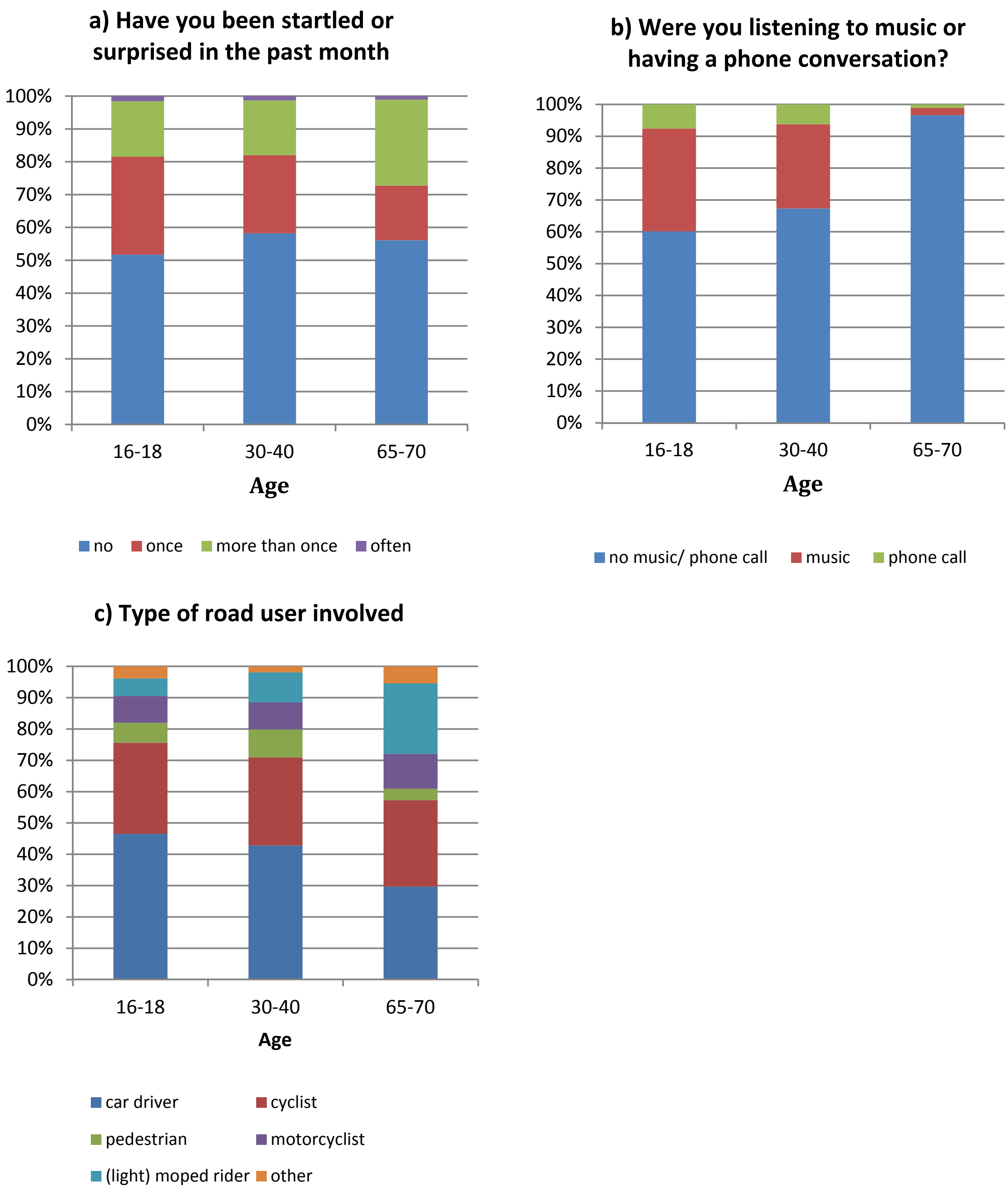

Figure 4. Startle/surprised reactions in the past month: (a) frequency, (b) relation with listening to music and talking on the phone and (c) other road users involved.

The majority of the teenage and middle-aged respondents and almost all of the older respondents were not listening to music or talking on the phone at that moment (60%, 67% and 97% respectively) (Figure 4b). Listening to music was more often reported that talking on the phone. Thirty-two percent of the teenagers, 26% of the middle-aged and only 2% of the older respondents were listening to music when they got startled/surprised versus respectively 8%, 6% and 1% of the respondents who were talking on the phone. The age differences were significant: ($\chi 2$=42.01; df=4; p<.001).

Finally, there were also differences between age groups with regard to the two questions about quiet, electric cars. Between 19 and 33% of the respondents (19% of older, 24% of teenage and 33% of middle-aged respondents) encountered quiet electric cars at least regularly (Figure 5a). In comparison with the two other age groups, a higher percentage of the older cyclists reported that they never encounter quiet (electric) car when cycling ($\chi 2$=58.2; df=10; p<.001). This result can however be caused by not knowing how an electric car sounds like (see Figure 5b) ($\chi 2$=34.0; df=10; p<.001).

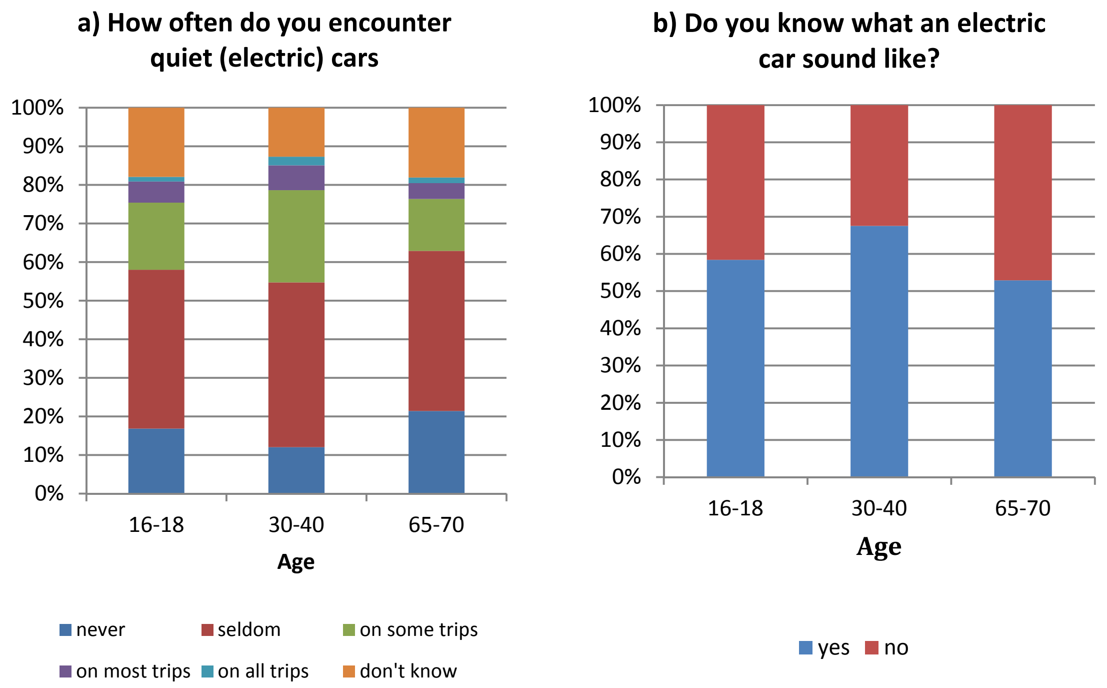

Figure 5. Cyclists' experiences with electric vehicles: a) frequency of encountering of quiet (electric cars and b) knowing what an electric car sound like per age group.

3.5 Compensatory behaviour

Compensatory behaviour for listening to music was reported by 65% of the teenage cyclist, 72% of the middle-aged cyclists and 70% of the older cyclists (no significant differences). The most often chosen types of compensatory behaviours for music were: looking around more frequently, turning the music down or off if it is necessary and using one earbud instead of two. The majority of the respondents (64% of teenage cyclists, 76% of middle-aged and 85% of older cyclists, age differences were significant: $\chi 2$=20.5; df=2; p<.001) reported refraining from listening to music in some specific traffic conditions, especially in bad weather, heavy traffic and complex traffic situations.

Compensatory behaviour for talking on the phone was reported by 67.4% of the teenage, 78% of the middle-aged and 79% of the older cyclists (no significant differences between age groups). The most often reported types of compensatory behaviour for having a phone call while cycling were: generally decreasing cycle speed and keeping the phone call short. Furthermore, the teenage and the middle-aged cyclists often reported looking around more frequently and cycling more slowly when approaching a complex traffic situation as a compensatory strategy. The majority of the respondents (77% of the teenage cyclists, 84% of the middle-aged and 82% of the older cyclists, age differences were significant: $\chi 2$=12.5; *df*=2; *p*=.002) reported refraining from listening to music in some specific traffic conditions, again especially in bad weather, heavy traffic and complex traffic situations.

3.6 Crash involvement

Crash involvement in the past 12 months was reported by 8% of the teenage cyclists; 4.9% of the middle-aged cyclists and 5.1% of the older cyclists (see Table 4). Two percent of bicycle crashes reported by the teenage and by the middle-aged cyclists was related to talking on the phone. Listening to music was associated with 6% of the crashes reported by the teenagers and 9% of the crashes reported by the middle-aged cyclists.

Table 4. Reported crashes per age group.

Age	16-18						30-40					65-70				Total nr of crashes
Nr of crashes	1	2	3	4	5	Total	1	2	3	4	Total	1	2	4	Total	
Frequency	52	5	2	1	2	82	27	7	2	1	51	33	5	1	47	180
Nr of crashes with known details						62					37				39	138

Table 5 shows that many crashes took place when the cyclist was ‘just’ cycling. The most often reported circumstance preceding or accompanying the crash was poor visibility. Quietness of other road user may have played a role in 5% of the crashes reported by the teenage cyclists and 2% of the crashes reported by the middle-aged cyclists. Environmental noise was present in 5% of crashes reported by the teenage and the middle aged cyclists. We can also notice that the older respondents differ strongly from the two younger groups. A great majority of the older respondents was ‘just cycling’ when the crash took place. The remaining other ones were busy or distracted by factors other than those specifically mentioned in Table 5.

Table 5. Specific circumstances preceding or accompanying the crash per age group.

	% of crashes		
	16-18	30-40	65-70
Just cycling	42	50	89
Poor visibility	17	11	0
Much environmental noise	5	5	0
Road user involved was very quiet	5	2	0
Talking on the phone	2	2	0
Talking to a fellow cyclist	9	7	0
Listening to music	6	9	0
Texting	0	7	0
Searching for information	5	5	0
Busy/ distracted by something else	9	2	11
Total	100%	100%	100%

3.7 Psychological determinants and risk behaviour

Age differences were found on the sensation seeking scale: *F(2,2248)*=128.73; *p*<.001. Teenage cyclists scored average (percentage true answers: 43%), middle-aged cyclists scored low (40%) and older adults very low on this personality trait (26.7%).

Respondents scored relatively low on the risk perception scale: *M*=2.4 for the teenage cyclists, *M*=2.6 for the middle-aged respondents and *M*=2.7 for the older respondents. The response options ranged from 1=*low risk perception* to 6=*high risk perception.* The age differences were significant: *F(2,2248)*=14.77; *p*<.001).

The respondents generally reported to be rarely involved in risk behaviour: *M*= 5.1 for the teenage respondents; *M*=5.3 for the middle-aged respondents and *M*=5.7 for the older respondents. The response option *5* indicated 'risk behaviour on some trips' and *6* indicated 'never'. The age differences were significant: *F(2,2248)*=162.61; *p*<.001

3.8 Impact of listening to music and talking on the phone for cycling safety

As mentioned in section 3.6 only 6.1% of the respondents reported having been involved in a bicycle crash. This low percentage did not allow for further statistical analysis. Therefore, the variable "startled/surprised" was chosen as an alternative indicator of cycling safety in the AMOS path analysis. Starling or getting surprised by another road user is a potentially dangerous situation as it implies a cyclist's failure to perceive the other road user or to understand their current behaviour in time. This failure can be linked to low situation awareness, unjustified expectancies/expectations and poor hazard anticipation (e.g. Kinnear et al., 2013) - concepts which have been linked to traffic safety.

As data were non-normally distributed maximum-likelihood (ML) estimation was used with bootstrapping (1,000 bootstrappings were performed). The hypothesized model shown in Figure 1 tested using the calibration sample, showed insufficient fit for all age groups. For the older age group, re-specification and re-estimation of the model in the post-hoc analysis did not result in an improvement of the model fit. For the middle-aged group, post-hoc model fitting resulted in a model that met the goodness-of-fit criteria. This model did not, however, fit the validation set. The cross-validation procedure was only successful for the youngest group. The final model obtained with calibration data also fitted the validation data. Table 6 presents the goodness-of-fit indices for the final solution for the calibration and the validation sample.

Table 6. Goodness-of-fit indices of the model for the calibration (N=374) and validation (N=374) and the whole sample (N=748).

	χ2(df)	*GFI*	*AGFI*	*RMSEA*	*pclose*	*p-value*
Calibration sample	*2.77(5)*	*.998*	*.988*	*.000*	*.94*	*.735*
Validation sample	*10.87(5)*	*.992*	*.954*	*.056*	*.35*	*.054*
Whole sample	*10.347(5)*	*.996*	*.978*	*.038*	*.69*	*.066*

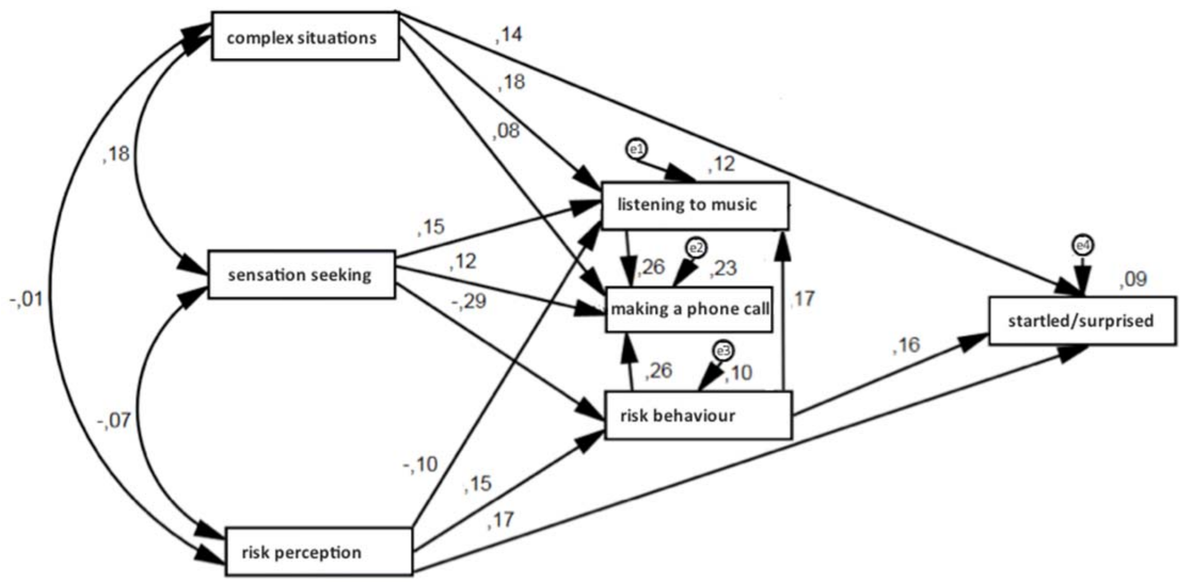

Figure 6. The final model; e1 to e4 represent error terms (residual variances within variables not accounted for by pathways hypothesized in the model).

Figure 6 shows the final model for the whole sample. Cycling exposure was not related to any other endogenous variables and was therefore removed from the model. Frequency of cycling in complex situations, sensation seeking and risk perception explained 23% of the total variance in 'Making a phone call', 12% of the total variance in 'Listening to music' and 10% of the total variance in 'Risk behaviour'. As indicated by the size of the standardised path coefficients (values above the arrows) most effects in the model are rather small, except for a medium effect of sensation seeking on 'risk behaviour' (.29). Sensation seeking is related to listening to music, making a phone call and risky cycling behaviour. Thus the higher the respondents' scores on sensation seeking, the more frequent they listen to music, talk on the phone and engage in risky behaviour while cycling. There was a small positive effect of the frequency of cycling in complex situations on the frequency of listening to music and talking on the phone.

However, the frequency of cycling of complex situations was not related to risky cycling behaviour. Risk perception was negatively related to listening to music suggesting that individuals with a higher risk perception, listen to music less often than those with a low risk perception. There was, however, a positive relationship between risk perception and risky cycling behaviour. Thus, the higher risk perception of cyclists, the more risky cycling behaviour reported by the teenagers. Figure 6 shows also that there is a positive relationship between making a phone call and listening to music. These two activities are related to risky cycling behaviour. Finally, we can see that 9% of the total variance in 'Startled/surprise' is explained by direct effect (.14) of 'Complex situation' and by indirect very small effect (.15*.16=0.02) and direct effect (.17) of 'Risk perception'. The frequency of cycling in demanding situations was related to the frequency of getting startled or surprised in traffic, but listening to music and talking on the phone were not.

4 DISCUSSION

This paper explored the impact of limited availability of auditory information among cyclists in three age groups in relation to two trends: listening to music and talking on the phone while cycling and the rising number of electric cars.

4.1 Age differences

A number of age differences were found in the present study. The greatest differences were generally found between the oldest respondents and the other two age groups. The differences between teenagers and middle-aged respondents were often less profound. Older cyclists were more often startled or surprised by other road users than were the other age groups. In contrast to the other age groups, these startle reactions of older respondents were hardly ever related to listening to music and talking on the phone. This result can be due to a very limited frequency of device use among the older adults. Results show that 77% of the teenagers, 42.5% of the middle-aged adults and only 6% of older adults reported listening to music while cycling. Similarly, 64% of the teenage, 43% of the middle-aged and only 10% of older respondents talk on the phone when cycling. If older respondents listen to music or talk on the phone, they do so rarely. Why older cyclist get startled or surprised more often than the other two age groups is not clear. Decreased hearing abilities could be (partly) the reason as fewer older adults reported good hearing than the middle-aged and teenage respondents.

4.2 Impact of listening to music and talking on the phone on auditory perception of cyclists

Listening to music has a greater impact on auditory perception of cyclists than talking on the phone. First of all, listening to music was found to be more popular among cyclists than talking on the phone. Second, in the age groups found to regularly listen to music and talk on the phone (teenagers and middle-aged adults) fewer respondents report that they can hear all or most sounds when listening to music than when talking on the phone. Finally, more cyclists report listening to music than talking on the phone as a circumstance preceding or accompanying getting startled or surprised by another road user.

4.3 Electric cars

The majority of the respondents indicated that they never or seldom encounter quiet (electric) cars when cycling. On the other hand, about 40% of the respondents do not know how an electric car sounds like. This seems in line with the limited share of (hybrid) electric cars in Dutch fleet. In January 2013, there were more than 90,000 fully electric and hybrid cars (of all types) in the Netherlands, which constitute 1.1% of the total number of Dutch cars. As the number of electric cars is growing (and many countries aim at increasing the number of those cars profoundly), the experiences of cyclists with electric cars can be different.

4.4 Impact of listening to music and talking on the phone on cycling safety

We found that the frequency of listening to music and talking on the phone while cycling was not related to the frequency of incidents as reported by teenage cyclists. This may be due to the fact that cyclists adapt their cycling behaviour to compensate for the use of portable devices. Compensatory behaviour was reported by about two-thirds of the teenage respondents. Another explanation for the lack of relationship might be behavioural adaptation of other road users who encounter a cyclist using electronic devices. Car drivers may, for example, adapt their behaviour to compensate for the possible dangerous behaviour of the cyclist, e.g. they may drive more carefully knowing that more and more cyclists are using various electronic devices.

4.5 Limitations

One of the limitations of this study is the use of subjective assessments, which can have important disadvantages (possible non-accurate recall and dishonest reporting, selective non-response bias, etc.). Another limitation regards the correlational design of the present study, which does not guarantee causal relationship between the variables.

4.6 Conclusion

This study shows that listening to music and talking on the phone impacts auditory perception of cyclists. The effects of listening to music seem to be more profound that these of talking on the phone. After controlling for the influences of psychological determinants, weekly time cycling, cycling in demanding cycling situations and various risk cycling behaviors, no association was found between listening to music or talking on the phone and safety incidents. This could well be due to compensatory behaviours of cyclists themselves. Cyclists tend to look around more often, turn the volume down or off, use one earbud instead of two, decease their speed and keep a phone call short. Additionally, other road users may compensate for the potential dangers of listening to music or talking on the phone.

This study shows that cyclists encounter quiet electric cars relatively rarely. Many cyclists do not know what electric cars sound like. This is likely to change in the near future as many counties aim to increase this type of cars profoundly. The question is whether cyclists in general - and those who listen to music or to talk on the phone in particular - will sufficiently compensate for the limited auditory input of electric cars. To answer this question more research is needed. As cyclists may not be aware of their actual cycling behaviour, future studies should explore compensatory behaviour of both cyclists themselves and other road users using more objective data.

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