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Mobile phone conversations, listening to music and quiet (electric) cars: Are traffic sounds important for safe cycling?

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ABSTRACT Listening to music or talking on the phone while cycling as well as the growing number of quiet (electric) cars on the road can make the use of auditory cues challenging for cyclists. The present study examined to what extent and in which traffic situations traffic sounds are important for safe cycling. Furthermore, the study investigated the potential safety implications of limited auditory information caused by quiet (electric) cars and by cyclists listening to music or talking on the phone. An Internet survey among 2249 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) the auditory perception of traffic sounds, including the sounds of quiet (electric) cars; 2) the possible compensatory behaviours of cyclists who listen to music or talk on their mobile phones; 3) the possible contribution of listening to music and talking on the phone to cycling crashes and incidents. Age differences with respect to those three aspects were analysed. Results show that listening to music and talking on the phone negatively affects perception of sounds crucial for safe cycling. However, taking into account the influence of confounding variables, no relationship was found between the frequency of listening to music or talking on the phone and the frequency of incidents among teenage cyclists. This may be due to cyclists' compensating for the use of portable devices. Listening to music or talking on the phone whilst cycling may still pose a risk in the absence of compensatory behaviour or in a traffic environment with less extensive and less safe cycling infrastructure than the Dutch setting. With the increasing number of quiet (electric) cars on the road, cyclists in the future may also need to compensate for the limited auditory input of these cars.

1.1. Introduction

For a cyclist auditory perception can be of great importance, especially for gathering information from areas outside his/her field of view, or when visibility is obstructed. Auditory cues, such as tyre and engine noises, may help to detect and localise approaching road users and orient cyclists' visual attention towards oncoming traffic. Recently, the use of auditory information by vulnerable road users, such as cyclists and pedestrians, may have become more challenging due to the growing number of electric (and hybrid) cars on the road. Electric cars are still relatively rare on our roadways. However, their number is expected to increase sharply as many European countries set ambitious sales or stock targets for electric cars in the near future (OECD/IEA, 2016). When driven at low speeds, cars in electric mode are generally quieter than conventional cars, especially in the built-up area where engine noise dominates. Slow moving (hybrid) electric cars are also detected later and localised less accurately by vulnerable road users than conventional cars, especially in environments with low ambient noise (Stelling-Kończak, Hagenzieker & Van Wee, 2015). Furthermore, electric cars driven at low speeds are localised less accurately than conventional cars, as found in a recent laboratory study including vehicle motion paths relevant for cycling activity (Stelling-Kończak et al., 2016). Also studies with drivers of electric cars suggest that cyclists have problems hearing these vehicles (Cocron & Krems, 2013; Hoogeveen, 2010). None of the drivers participating in these studies reported a noise-related crash. However, a substantial percentage of drivers (45% in the study of Hoogeveen and 67% in the study of Cocron & Krems) reported noise-related incidents, especially at low speeds, e.g. pedestrians and cyclists missing the electric car or getting startled or surprised by its approach.

Besides electric cars, the increasing use of mobile technology while cycling can also make it more difficult for cyclists to utilize auditory cues. A field study by de Waard et al., (2011) has shown that listening to music and talking on the phone impairs cyclists' perception of relevant traffic sounds such as the sound of a bicycle bell. In this study high tempo music, loud music and in particular music listened through in-earphones has been found to impair even hearing of loud sounds, that is, horn honking. Talking on the phone and listening to music are quite popular among cyclists, especially youngsters. In a Dutch survey, 76% of the teenage cyclists but only 14% of the cyclists older than 50 years old reported listening to music. In the same study, 77% of the teenage cyclists and 34% of the older cyclists reported using a mobile phone while cycling (Goldenbeld et al., 2012).

The role of auditory information in cycling has only recently become the topic of scientific research. According to the conceptual model of Stelling-Konczak, Hagenzieker & van Wee (2015), restricted auditory perception can have consequences for cycling safety (see *Figure 1.1*). Being unable to hear traffic sounds can negatively affect cyclists' situation awareness[1] and cycling performance. In the presence of traffic-related hazards, a degraded cycling

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[1] Situation awareness refers to the awareness of the meaning of dynamic changes in the environment (Endsley, 1995), e.g. the awareness of approaching vehicles.

performance can in turn lead to crashes if it is not sufficiently compensated by the cyclist himself or other road users involved. The conceptual model in *Figure 1.1* also acknowledges the importance of cyclist characteristics (biological, sociocultural, traffic- related and temporary factors) and of the traffic environment (e.g. road infrastructure, weather, traffic-related conditions) when studying the relationship between restricted auditory perception and cycling safety.

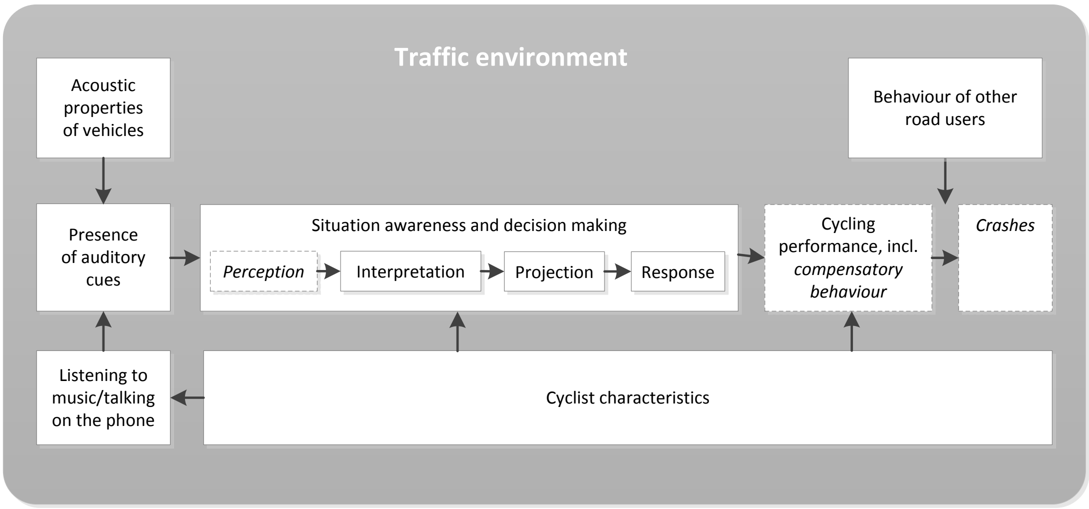

Figure 1.1. Conceptual model of the role of auditory information in cycling safety (adapted from Stelling-Kończak, Hagenzieker & Van Wee, 2015). Knowledge gaps are marked by dashed boxes.

To date, little research has been done into the impact of device use while cycling or of the quietness of electric cars on cycling safety. In their review article Stelling-Konczak et al., Hagenzieker & van Wee, (2015) identify a number of important knowledge gaps which need to be addressed for a better understanding of the relationship between limited auditory information and cycling safety.

To begin with, little is known about the auditory perception of cyclists who listen to music or talk on the phone. Phone conversation and music was found to deteriorate the detection of traffic sounds, i.e. the sound of a bicycle bell and a horn honking (De Waard, Edlinger & Brookhuis, 2011). There are two potential explanations for these negative effects. Music and telephone conversation may cause distraction by diverting attention away from the traffic task toward inward experiences (thoughts, memories, emotions, moods) (see for example Herbert, 2013; Strayer et al., 2013). The other explanation concerns auditory masking: the phenomenon that occurs when one sound (e.g. music or speech) prevents or blocks the perception of another sound (e.g. a sound of an approaching car). Auditory masking is a complex phenomenon and the potential of a sound to be masked depends on the frequency and intensity of that sound (see e.g. Baldwin, 2012). Given the complexity of the masking phenomenon, the results of prior research into cyclists' auditory perception do not allow conclusions about the influence of listening to music or talking on the phone on the perception of other traffic sounds such as the sounds of cars, whether they be conventional or electric cars.

Next, not much is known about the potential compensatory behaviour of cyclists who listen to music or talk on the phone. In the only study that we could find, an Internet survey by Goldenbeld et al. (2012), two-third of the cyclists reported adjusting their behaviour when using portable devices. The most popular type of compensatory behaviour among older cyclists was wearing a bicycle helmet and refraining from using portable devices in demanding traffic situations. Younger cyclists reported compensating for the use of devices mainly by paying more attention to traffic. Compensatory behaviour in that study was examined for device use in the aggregate (consisting of listening to music, having a phone conversation, texting and searching for information). We therefore do not know to what extent cyclists specifically listening to music or talking on the phone engage in compensatory behaviour.

Furthermore, very little research has been done into the impact of device use or the quietness of electric cars on cyclists' crash involvement. The only study into the effect of mobile devices on cyclists' crash risk we have been able to find (Goldenbeld et al., 2012) showed that using a mobile device was associated with an increased risk of self-reported bicycle crash involvement. The study controlled for the influence of a number of cyclist characteristics and factors in the traffic environment (i.e. age, urbanization, cycling time, and cycling in demanding situations). The overall risk of a self-reported crash for cyclists who used electronic devices on every trip was found to be a factor 1.6 higher for teenagers and a factor 1.8 higher for young adults compared with their respective age counter- parts who never used devices while cycling. Apparently the compensatory behaviour of young cyclists is not sufficient to counterbalance all the risks associated with the use of electronic devices. The crash risk of individual tasks was not examined in that study and thus remains unknown. Some individual tasks may pose a higher safety risk than others. Texting and searching for information are activities that do not require auditory but mainly visual perception and attention, and are considered riskier than listening to music or talking on the phone.

As concerns electric cars, their safety performance cannot be easily compared to that of conventional cars, primarily due to the lack of exposure data (i.e. kilometres travelled) for both car types. Some studies show higher incidence rates[2] of crashes involving hybrid or electric cars and vulnerable road users (Hanna, 2009; Morgan et al., 2011; Wu, Austin & Chen, 2011). However, as these incidence rates are not corrected for exposure, there is no evidence that hybrid or electric cars pose a higher safety hazard for pedestrians and cyclists than conventional cars (see Verheijen & Jabben, 2010).

1.1.1. This study

The present study addresses the three aforementioned research gaps in the relationship between limited auditory information and cycling safety. A sample of over 2200 respondents in three age groups (teenage, adult and older cyclists) completed an Internet survey. The teenagers and the elderly were the main focus of the study, as these age groups are particularly vulnerable in terms of cycling safety. In the EU countries, cyclists of 65 years and older represent a large proportion of cyclist fatalities (37%). There is, furthermore, a peak in fatalities among teenage cyclists of 12–17 years old, the age of increasing cycling autonomy (Candappa et al., 2012). Older and teenage cyclists are also of interest from the perspective of the auditory perception of traffic sounds: young cyclists because of their frequent use of devices, the elderly due to the decline in hearing abilities in old age (e.g. Schieber & Baldwin, 1996; Van Eyken, Van Camp & Van Laer, 2007).

Our study has three aims. The first objective was to explore self-reported auditory perception of traffic sounds, including the sounds of quiet (electric) cars, among cyclists of the three age groups. As listening to music and talking on the phone were found to impair the hearing of a bicycle bell (De Waard, Edlinger & Brookhuis, 2011), we could expect that cyclists'

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[2] Incidence rates = the number of vehicles of a given type involved in crashes with a pedestrian or bicyclist divided by the total number of that type of vehicle that were involved in any crashes.

perception of other traffic sounds, e.g. the sounds of cars (especially quiet electric cars) will at least to some extent be compromised by listening to music or talking on the phone. As electric cars are still quite rare on Dutch roads we expected that cyclists would probably not have much experience with the auditory characteristics of these cars. The second aim was to examine to what extent cyclists in the three age groups compensate for listening to music or talking on the phone. Based on earlier research (Goldenbeld et al., 2012), we expected age differences in the frequency of listening to music and talking on the phone as well as in the reported compensatory behaviour.

The third aim was to investigate for each age group the extent to which listening to music and talking on the phone impact cyclists' involvement in self- reported crashes and incidents. Listening to music or talking on the phone, although considered less dangerous than activities involving manual phone manipulation, may still pose a safety risk to cyclists. On the other hand cyclists may sufficiently compensate for these risks by adapting their behaviour. While assessing the contribution of listening to music and talking on the phone to cycling crashes and incidents, we attempted to control for potentially risk-increasing cyclists characteristics and aspects of the traffic environment. The influence of two aspects of the traffic environment was taken into account, i.e. the time spent cycling and the exposure to complex traffic situations (i.e. cycling in darkness, etc.). These two aspects were chosen as they were found to be significant predictors of crash involvement among cyclists in the study of Goldenbeld et al. (2012). With regard to cyclist characteristics, sensation seeking and impulsivity have been found to correlate positively with both self-reported and police-recorded motor vehicle crashes (Dahlen & White, 2006; Iversen & Rundmo, 2002; Stevenson et al., 2001). This relationship is either direct or indirect, the relationship being mediated by risky driving behaviours in the latter case. Furthermore, a study with adult non-motorized road users (i.e. e- bike riders) has shown that risk perception, attitudes towards safety and responsibility are associated with risky riding behaviour (Yao & Wu, 2012). Given the length of the survey and the time commitment required to complete it, we investigated the effects of only two psychological determinants: risk perception and sensation seeking on the (self-reported) crash involvement of cyclists. At the same time, we also corrected for the influence of other risky cycling behaviour which may accompany listening to music or talking on the phone.

1.2. Methods

1.2.1. Survey sampling and administration

An online data collection procedure 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 online between 13 and 30 June 2014 via a survey company that maintains an online panel of respondents. Data was collected from a total of 2249 respondents in three age groups: young (16–18 years old; N = 748), adult (30–40 years old; N = 749) and older cyclists (65–70 years old; N = 752). Half of the respondents in each age group were female. Respondents were included if they cycled at least once a week and had no major hearing deficiencies. The sample was representative of the national Dutch population in terms of educational level and regional distribution. Since the respondents were recruited from the cycling population, they may not be representative for the average Dutch person in terms of cycling time (see also *Section 1.3.3*)[3]. The survey took about 20 minutes to complete.

1.2.2. Questionnaire

The questionnaire consisted of three parts. Part 1 contained questions about demographics, exposure and bicycle use in general and in demanding situations. The elicited cyclists' characteristics included gender, age, hearing abilities and the type of school they had attended or were still attending. Furthermore, respondents were asked about their helmet use, the type of bicycle they usually use and whether they cycle alone or accompanied by others. The time spent cycling was measured with two items: the 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 consisting of 6 items was used to measure the frequency of cycling in demanding traffic situations, specifically cycling: in darkness, through intersections, roundabouts or crossings of the road, in heavy traffic, while sharing the road with motor vehicles, in heavy bus/truck traffic, in heavy

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[3] The average weekly amount of time spent cycling in the Netherlands is: about 201 min for teenagers 12–18 years old, 70 min for adults 30–40 years old and about 95 min for adults 65–70 years old (Fishman et al., 2015; Statistics Netherlands, 2016). Unfortunately no data is available on the average weekly amount of time spent cycling among the population of cyclists in the Netherlands.

(light) moped traffic (answer options: *0 = never*; *1 = seldom*; *2 = on some bicycle trips*; *3 = on most bicycle trips*, *4 = on all bicycle trips*).

Part 2 included questions about the use of electronic devices, auditory perception of traffic sounds and compensatory behaviour while using devices. The measurement items are detailed in *Table 1.1*. Respondents were asked about the frequency of device use, i.e. listening to music, talking on the phone, texting and searching for information on the phone while cycling in general and while cycling in more demanding traffic situations described above. Questions about texting and searching for information were asked to

Table 1.1. Items in Part 2 of the questionnaire.

Measures	Items	Answer options:
Use of electronic devices	How often do you: • listen to music • talk on the phone • text • search for information on the phone during an ordinary cycling week? while cycling in demanding traffic situations?	never/ seldom/ on some bicycle trips/ on most bicycle trips/ on all bicycle trips
	How do you usually listen to music? How do you usually talk on the phone?	2 earbuds/1 earbud/ 2 in-earbuds/1 in-earbud/ headphones/loudspeaker/alternating
Auditory perception	How much sound can you hear when: • you listen to music while cycling? • you talk on the phone while cycling? How much sound should a cyclist hear to be able to cycle safely?	nothing at all/ not much/ only loud or sharp sounds/ most sounds/ all sounds/ don't know
	How often do you encounter a quiet (electric) car while cycling?	never/ seldom/ on some bicycle trips/ on most bicycle trips/ on all bicycle trips/ don't know
	Do you know what an electric car sounds like?	yes/no
Compensatory behaviour	What do you usually do when you get called when cycling?	I do not get called when cycling/ I answer the phone and I have a conversation / I answer the phone but I try to keep the conversation short/ I answer the phone to say that I will call back later/ I stop/get off my bicycle to answer the phone/I decline the phone call/ I ignore the phone call/ something else, please specify
	What do you usually do when they want to call someone when cycling	I make a phone call while cycling/ I wait until I reach my destination/ I stop/get off my bicycle to make a phone call/ I postpone a call until I reach a less busy location/ I choose a different route and I make a call while cycling/ something else, please specify
	Do you adapt your cycling behaviour when listening to music? Do you adapt your cycling behaviour when talking on the phone?	No, I do not adapt my behaviour/ Yes: *(more than one answer allowed)* - I look around more often (*M*, *P**); - I cycle more slowly (*M*, *P*); - I slow down when approaching an intersection or a complicated traffic situation (*M*, *P*) - I choose other routes (*M*, *P*); - I choose other cycling times (*M*, *P*) - I listen to music through 1 earbud instead of 2

	(*M*); - I turn the volume down when necessary (*M*) - I keep the conversation short(*P*) - something else, please specify (*M, P*)
Are there any specific traffic conditions in which you choose not to listen to music? Are there any specific traffic conditions in which you choose not to talk on the phone?	No, I listen to music/talk on the phone irrespective of traffic situation/ Yes: *(more than one answer allowed)* - when the visibility on the road is decreased, - with bad weather; - when it is busy; - in complex traffic situations; - with unknown routes; - when I ride a heavy or unstable bicycle; - when I ride a bicycle which is too small, too large or not mine; - when I feel sick; - something else, please specify

** M: options for 'listening to music'; P: options for 'talking on the phone'*

place the frequency of listening to music and talking on the phone in the perspective of other activities which electronic devices (smartphone) offer. Respondents had also to indicate the manner of listening to music and talking on the phone. To measure auditory perception 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. Additionally, the respondents were asked two questions about quiet, electric cars: how often they encounter a quiet (electric) car when cycling and whether they know what an electric car sounds like. Compensatory behaviour was measured by asking respondents what they usually do when they get called and what they usually do when they 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 the type of behaviour. 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.

Part 3 contained questions about sensation seeking, risk perception, risky cycling behaviour and involvement in traffic incidents and crashes. Sensation seeking (i.e. the need for excitement and stimulation) was measured with the Dutch Impulsive Unsocialized Sensation Seeking (ImpSS) scale consisting of 19 forced-choice items with answer true or false and involving items concerning 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; 1994). 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 analyses. A high score on the scale indicated a high level of sensation seeking. Risk perception was measured with 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.

Risky cycling behaviour was measured with an adapted version of the Adolescent Road Behaviour Questionnaire (ARBQ) (Twisk et al., 2015). The ARBQ, originally developed by Elliott and Baughan (2004), is based on Reason's classification of road user behaviour (Reason, 1990). Twisk et al. (2015) adapted the original ARBQ to study pedestrian and cyclist behaviour. Most of the items to measure risky cycling behaviour in the present study were selected from this modified Adolescent Road Behaviour Questionnaire. Instead of the full set of four types of risky behaviour used by Twisk et al., we only included the items measuring the following three types of risky behaviour: violations, errors and lack of protective behaviour. Violations are deliberate deviations from normal safe practice or socially accepted codes of behaviour while errors refer to failures of planned actions to achieve intended consequence (Reason, 1990). Lack of protective behaviour concerns the 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). Two items relating to adolescent-specific behaviours were replaced by age-neutral items. Furthermore, some items concerning pedestrian behaviour were replaced by items specific to cycling behaviour. In the end, risky cycling behaviour was measured with a total of 24 items, consisting of three subscales. Each subscale comprised of 8 items. Responses to the items consisted of six-point Likert scales (with categories ranging from *1 = never* to *6 = always*).

With regard to traffic incidents respondents were asked whether they had got startled or surprised by some other road user in the past month (answer options: *0 = no, 1 = once, 2 = more than once, 3 = often*), and if so to give some more details about the (most recent) case (such as the reason for getting startling, the type of road user involved and whether the respondents were listening to music or talking on the phone at that time). 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.).

1.2.3. Analysis

The reliability and internal consistency of the items measuring risk perception (4 items), sensation seeking (19 items), risky behaviour (24 items) and exposure to demanding cycling situation (6 items) were assessed using Cronbach's alpha. Items with values of Cronbach's alpha equal to or larger than 0.70 were considered internally consistent (Kline, 1999). Moreover, to investigate whether empirical confirmation could be found for the hypothesis that the 24 items of the risk behaviour scale can be decomposed into the three distinct subscales Errors, Violations and Lack of protective behaviour (each consisting of 8 items) a categorical principal component analysis (CATPCA) was performed in SPSS treating all 24 items on an ordinal measurement level. CATPCA is a data reduction technique appropriate for numerical, ordinal and nominal 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 is obtained where the respondents (called objects in CATPCA) are represented as points and the items are represented as vectors (Gifi, 1990). The closer points are located together, the more similar are the answer profiles of the respondents concerned. The angles between the vectors are a function of the relationships between the items they represent: angles close to 0 (180) degrees indicating strong positive (negative) relationships between items, and angles close to 90 and 270 ° indicating weak relationships between items. The coordinates of the points on the components are called object scores and can be used in further analyses as quantifications of the respondents on the latent variables represented by each component.

Bivariate analyses were used to investigate possible differences between the three age groups. When the dependent variable was numerical one-way analysis of variance (ANOVA) was used to test for differences; when the dependent variable was nominal a chi-square test was used instead.

Path analysis in AMOS (22.0) for SPSS was performed to investigate the multiple linear relationships between the variables in the path model shown in *Figure 1.1* (see the *Results* section for further details). In path analysis an observed variable may be simultaneously treated as an independent (exogenous) and a dependent (endogenous) variable. Specifically, in this study, a path analysis can be used 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 hypothesized model and the data (Bagozzi & Heatherton, 1994). Significant values of the chi-square test indicate a strong divergence between the data and the fitted model.

1.3. Results

1.3.1. Reliability and internal consistency of measures

For most of the 24 risk behaviour items of the questionnaire high scores on the items indicated non-risky behaviour, except for four items for which high scores indicated very risky behaviour. Before analysing the risk behaviour items with a categorical principal component analysis (CATPCA), these four items were recoded in such a way that high scores also indicated non-risky behaviour. Using the eigenvalue- larger-than-one criterion (see e.g. Tabachnick & Fidell, 2007) a first two-dimensional solution with the CATPCA was found accounting for 55.1% of the variance in the data (the first component accounted for 49.6% and the second for 5.5% of the total variance). All items had high positive loadings on the first component except for the four recoded items consisting of one Error-item and three Lack of protective behaviour- items who all had high positive loadings on the second component. This suggests that the respondents were more sensitive to the reversed wording of these four items than to their actual content. A second ordinal CATPCA without the latter four items again yielded a two-dimensional solution, now accounting for 57.8% of the total variance in the data (with 51.7% on the first and 6.1% on the second component). Now all the remaining 20 items had higher (positive) loadings on the first than on the second component, see *Table 1.2*. Moreover, the loadings on the second component did not discriminate between the Error-, the Violation- and the Lack of protective behaviour-items meaning that no confirmation was found for the hypothesized three-factor structure in the risk behaviour scale.

Table 1.2. Component loadings of the second CATPCA of 20 risk behaviour items (E = Error, V = Violation, L = protective behaviour).

	Dimension 1	Dimension 2
RB 1 (E)	0.802	−0.186
RB 2 (E)	0.699	0.325
RB 3 (L)	0.719	0.380
RB 4 (L)	0.810	−0.011
RB 6 (E)	0.745	0.112
RB 8 (E)	0.662	−0.273
RB 9 (V)	0.794	−0.189
RB 10 (V)	0.734	−0.118
RB 12 (V)	0.659	0.343

RB 13 (E)	0.731	−0.291
RB 14 (V)	0.804	−0.215
RB 15 (E)	0.748	−0.345
RB 16 (L)	0.589	0.364
RB 17 (L)	0.790	−0.092
RB 18 (V)	0.807	−0.207
RB 19 (V)	0.582	0.101
RB 20 (V)	0.637	0.392
RB 22 (L)	0.660	0.123
RB 23 (E)	0.649	−0.154
RB 24 (V)	0.689	0.212

The value of Cronbach's α for the 20 items in the second analysis is 0.94, whereas it is 0.88 for the full set of 24 items, confirming that the internal consistency of the 20 items is indeed better than that of the full risk behaviour scale. Since the first component of the second CATPCA could clearly be interpreted as a general risk behaviour component, the object scores of the respondents on this component were used as a latent risk behaviour variable in all further analyses, high scores being indicative of risky behaviour.

1.3.2. Respondent characteristics

The majority of the respondents reported good hearing (89.2% of cyclists aged 16–18 years: 84.6% of cyclists aged 30–40 years and 66.0% of cyclists aged 65–70 years). Most respondents (84.5%) usually cycled on a conventional bicycle (a ladies' bike or a men's bike). However, much more respondents (20%) in the oldest group usually cycled on an e-bike than the other age groups (2.7% of teenage and 0.5% of adult cyclists). The majority of the respondents cycled alone or more often alone than in company of other cyclists.

1.3.3. Time spent cycling and exposure to demanding situations

Teenagers spent significantly more time cycling (M = 262 min a week) than the adult (M = 179 min a week) and older respondents (M = 240 min a week): $F(2, 2248) = 8.25$; $p < 0.001$. The value of Cronbach's α for the 6 items measuring exposure to demanding situations is 0.84, indicating an internally consistent scale. Post-hoc tests with Bonferroni correction (see e.g. Kirk, 2012) applied to this scale revealed that teenagers and adult respondents cycled more often in demanding situations (respectively: M = 3.35, SD = 0.70 and

$M = 3.30$, $SD = 0.75$) than the older cyclists ($M = 2.92$, $SD = 0.76$): $F(2, 2248) = 77.20$, $p < 0.001$).

1.3.4. Use of electronic devices

There were significant differences between age groups regarding frequency of listening to music ($\chi 2 = 847.4$; $df = 8$; $p < .001$), making a phone call ($\chi 2 = 459.8$; $df = 8$; $p < .001$), answering the phone ($\chi 2 = 409.8$; $df = 8$; $p < .001$), reading ($\chi 2 = 748.7$; $df = 8$; $p < .001$) and typing text messages ($\chi 2 = 734.3$; $df = 8$; $p < .001$), but no significant age differences were found concerning searching for information. Teenage respondents were the most frequent users of electronic devices while the oldest respondents rarely used electronic devices (see *Table 1.3*).

Listening to music while cycling was especially popular among teenage cyclists. It was reported by 77% of the teenage respondents, 43% of the adult respondents but only by 6.2% of the oldest respondents. Almost a quarter of the teenage cyclists reported listening to music on each trip. Listening to music was the most frequent device use among the teenagers while making a phone call was the least popular among this age group. Device use among adult cyclists is more homogeneous. About the same percentage of the adult respondents (40–45%) reported listening to music, making a phone call or texting while cycling. Searching for information was reported by about one-third of the adult cyclists. Those who use devices do so rather infrequently. As far as the oldest group is concerned, only 6–10% of cyclists in this age group reported using devices while cycling. The older adults who use devices do so only rarely.

Table 1.3. 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.

		Percentage of cyclists			
Age group	**Frequency of use**	**Listening to music**	**Making a phone call**	**Texting: reading/typing**	**Information search**
16-18	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	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	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 both earbuds (reported by about 40% of the respondents) followed by using one earbud (chosen by 21–23% of the respondents) (*Table 1.4*). The manner of listening to music differed significantly 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 adult cyclists but by none of the older cyclists. There were also significant differences between age groups concerning the frequency of listening to music while cycling in demanding situations (F (2940) = 15.28, $p = .00$). The older cyclists refrained most often ($M = 2.62$, $SD = 0.98$) and the teenage cyclists ($M = 1.91$, $SD = 0.98$) least often from listening to music while cycling in demanding situations, with the adult cyclists taking in a middle position ($M = 2.16$, $SD = 1.03$). All pairwise post-hoc tests were significant.

Table 1.4. Percentage of cyclists reporting specific manners of listening to music per age group.

	Age group		
	16-18	**30-40**	**65-70**
2 earbuds	40.6	38.7	40.4
1 earbud	22.6	22.3	21.3
2 in-earbuds	15.5	16.4	0
1 in-earbud	6.6	7.5	2.1
Headphone	4.5	5.7	4.3
Loudspeaker	3.8	5	8.5
Alternating	6.4	4.4	23.4
Total	*100*	*100*	*100*

1.3.5. Auditory perception

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 (*Figure* 1.2*a*).

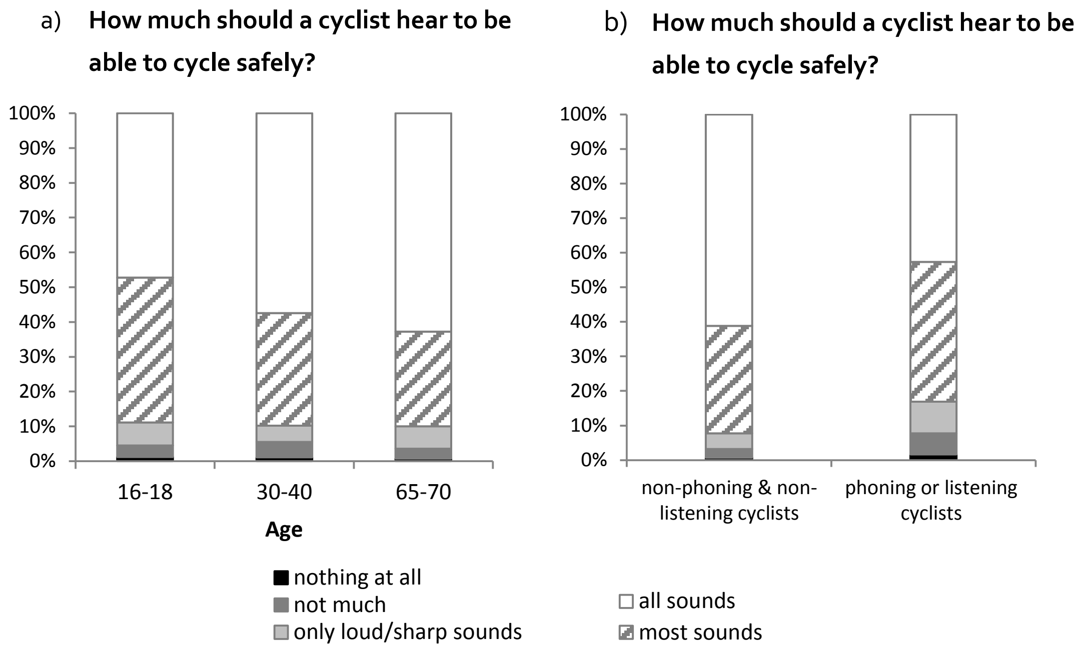

Figure 1.2. The extent to which cyclists should hear traffic sounds to be able to cycle safely per age group (a) and per type of cyclist (phoning/listening to music versus non-phoning/ listening to music) (b).

A higher percentage of the older respondents (63%) than teenage (47%) or the adult respondents (57%) reported that cyclists should be able to hear all sounds. These age differences were significant: ($\chi 2$ = 47.0; *df* = 8; $p < .001$). 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.

Figure 1.3a 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 adult cyclists (no test possible: chi-square test was invalid). With regard to talking on the phone, 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. The age differences found were significant: ($\chi 2$ = 42.0; *df* = 10; $p < .001$).

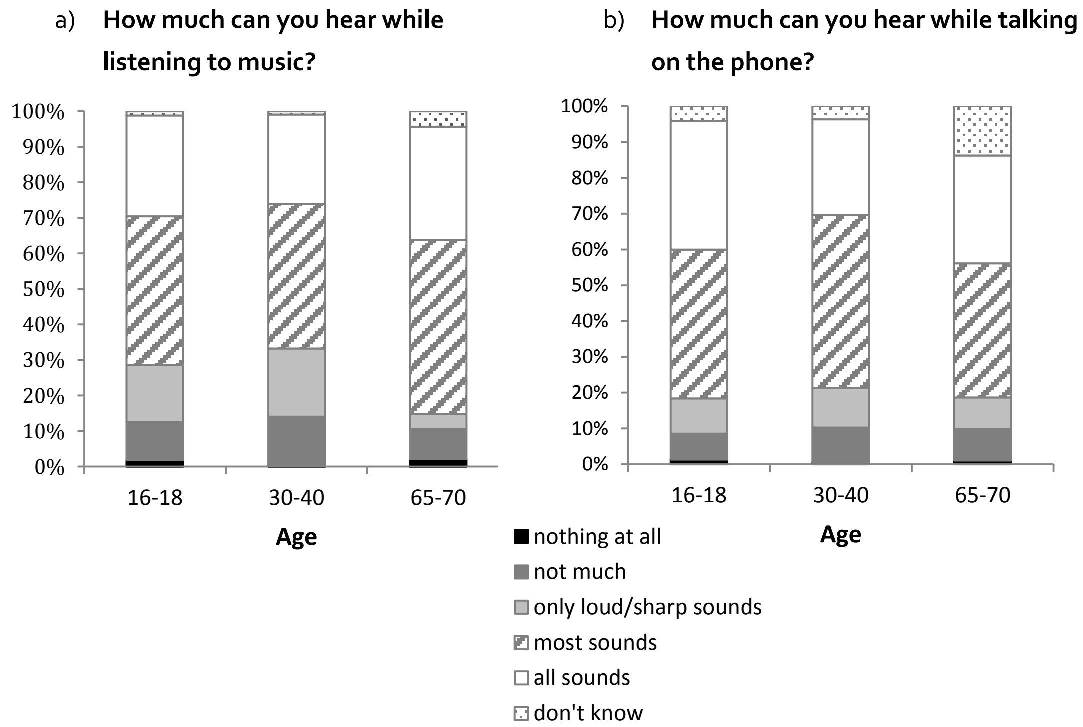

Figure 1.3. The extent to which cyclists can hear sounds when and listening to music (a) and talking on the phone (b) per age group.

When comparing *Figures 1.2a* with 1.*3a* and 1.*3b*, we can see that, according to the respondents 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 compared to cyclists who listen to music and/or talk on the phone, a higher percentage of cyclists who never engage in those activities indicated that cyclists should hear all sounds in order to cycle safely ($\chi 2$ = 78.6; *df* = 4; *p* < .001) (*Figure 1.2b*).

Finally, there were also significant differences between the age groups with regard to the two questions about quiet (electric) cars. Between 19 and 33% of the respondents (19% of the older, 24% of the teenage and 33% of the adult respondents) encountered (quiet) electric cars at least regularly (*Figure 1.4a*). 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). About 47–32% reported not knowing how an electric car sounds like (see *Figure 1.4b*) ($\chi 2$ = 34.0; *df* = 10; *p* < .001).

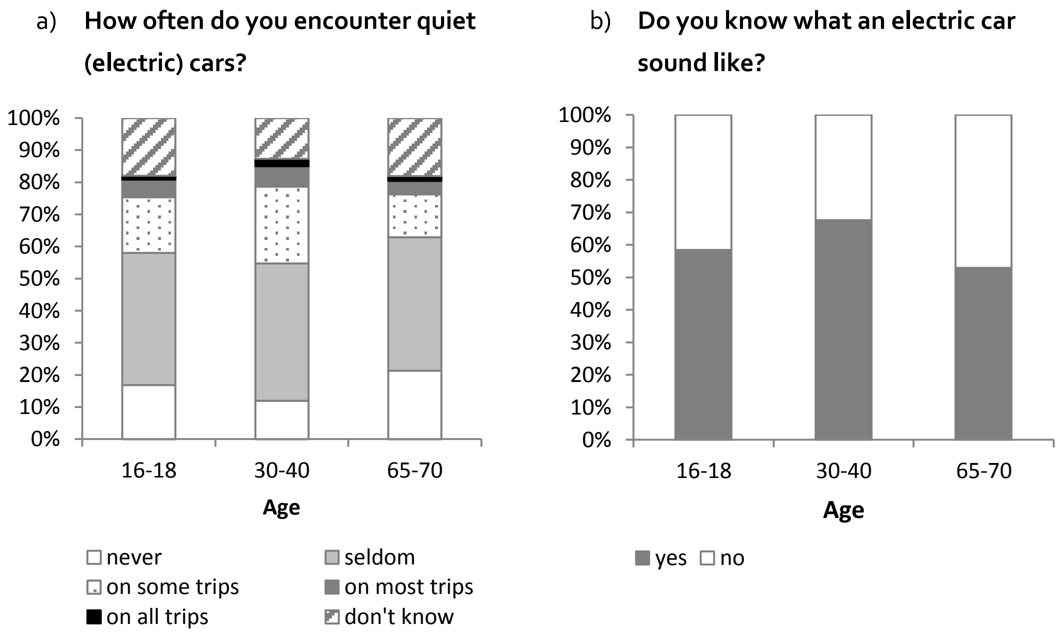

Figure 1.4. Cyclists' experiences with electric vehicles: a) frequency of encountering of quiet (electric cars and b) knowing what an electric car sound like per age group.

1.3.6. Compensatory behaviour

In comparison with adult and older cyclists, a lower percentage of teenage cyclists reported adapting their behaviour to compensate for listening to music or talking on the phone. Compensatory behaviour for listening to music was reported by 65% of the teenage cyclist, 72% of the adult cyclists and 70% of the older cyclists (but these differences are not significant). 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 the teenage, 76% of the adult and 85% of the older cyclists, these age differences being 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 adult and 79% of the older cyclists (but these differences are not significant). 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 adult 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, 84% of the adult and 82% of the older cyclists, these age differences being significant: $\chi 2 = 12.5$; $df = 2$; $p < .01$) reported refraining from listening to music in some specific traffic conditions, again especially in bad weather, heavy traffic and complex traffic situations.

1.3.7. Sensation seeking

The value of Cronbach's α for the 19 items of the sensation seeking scale is 0.83, indicating an internally consistent scale. Significant age differences were found for this scale: $F(2, 2248) = 128.73$; $p < .001$. Teenage cyclists scored average (percentage true answers: 43%), adult cyclists scored low (40%) and older adults very low on this personality trait (26.7%).

1.3.8. Risk perception

The value of Cronbach's α for the 4 items of the risk perception scale is 0.91, again indicating an internally consistent scale. Respondents scored relatively low on the risk perception scale: $M = 2.4$ for the teenage cyclists, $M = 2.6$ for the adult respondents and $M = 2.7$ for the older respondents, the response options ranging from *1* = low risk perception to *6* = high risk perception. These age differences in risk perception were significant: $F\ (2, 2248) = 14.77$; $p < .001$.).

1.3.9. Risky cycling behaviour

We found significant differences between the object scores of the three age groups on the general risky behaviour component obtained from the CATPCA (see *Section 1.3.1*): $M = -0.364$ for the teenage respondents; $M =$

−0.065 for the adult respondents and *M* = 0.426 for the older respondents ($F(2,2246) = 133.37$, $p < 0.001$). Since high scores correspond with non-risky behaviour, the older age group displays the safest behaviour on average.

1.3.10. Incidents

Significant differences in the frequency of getting startled or surprised by some other road user in the past month were found also between age groups ($\chi 2 = 54.1$; $df = 6$; $p < .001$) (*Figure 1.5a*). More than half of the respondents in each group had never got startled or surprised in the past month (52% of teenage, 58% of the adult and 56% of the older cyclists). A higher percentage of the older respondents got startled/surprised 'more than once' as compared to the teenage or adult respondents.

The teenage and adult respondents got startled or surprised especially by car drivers and cyclists. The older respondents got also often startled or surprised by (light) moped riders ($\chi 2 = 70.2$; $df = 10$; $p < .001$) (*Figure 1.5b*). Not hearing another road user was reported as a cause of the incident by 28% of the adult, 30% of the teenage and 39% of the older cyclists. The age differences were significant, ($\chi 2 = 8.96$; $df = 2$; $p < .05$).

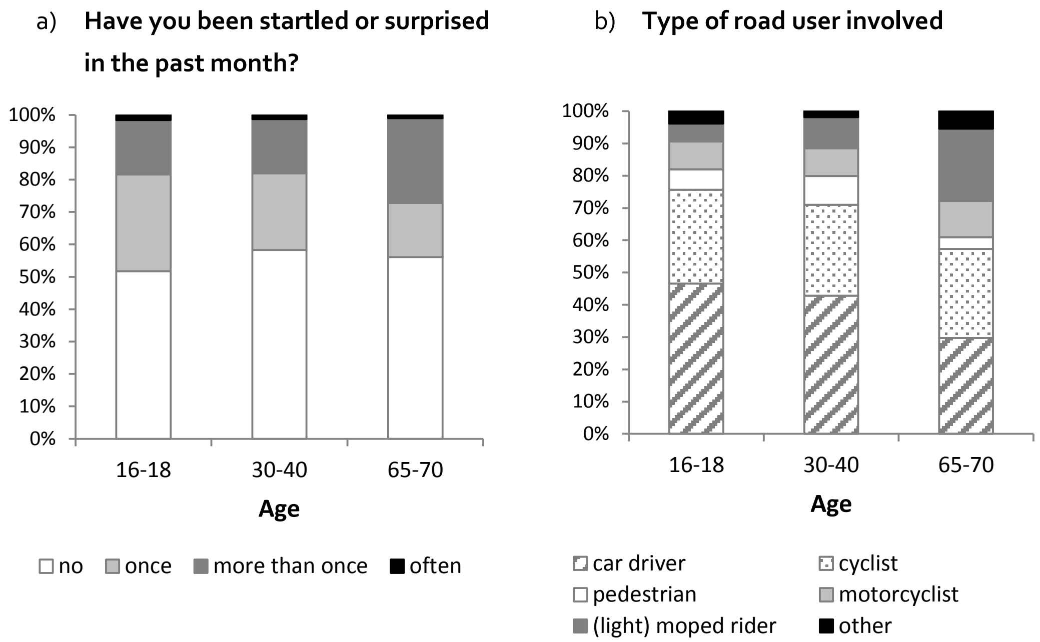

Figure 1.5. Startle/surprised reactions in the past month: (a) frequency of music and talking on the phone and (b) other road users involved.

1.3.11. Crashes

Crash involvement in the past 12 months was reported by 8% of the teenage cyclists; 4.9% of the adult cyclists and 5.1% of the older cyclists (see *Table 1.5*). As respondents who were involved in more than one crash were asked to provide further details about the most recent crash, the total number of crashes (*N* = 180) is higher than the number of crashes with known details (*N* = 138). As a result the details about 42 crashes are not known.

Details regarding specific circumstances preceding or accompanying the crash are summarized in *Table 1.6*. As we can see many crashes took place when the cyclist was 'just' cycling. The most often reported circumstance preceding or accompanying the crash was poor visibility.

Table 1.5. Reported crashes per age group.

	Age group																
	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	3	4	Total	
Frequency	52	5	2	1	2	82	27	7	2	1	51	33	5	0	1	47	180
Nr of crashes with known details*						62					37					39	138

**When more than one crash was reported by a respondent, details were asked about the most recent crash.*

Crashes in which limited auditory perception, marked grey in *Table 1.6*, might have played a role constitute 13% of all crashes with known detail. Surprisingly, none of the older respondents reported getting involved in these crashes. Quietness of other road users may have played a role in 5% of the crashes reported by the teenage cyclists and 2% of the crashes reported by the adult cyclists. Environmental noise was present in 5% of crashes reported by the teenage and the middle aged cyclists. Two percent of bicycle crashes reported by the teenage and by the adult cyclists was related to talking on the phone. Finally, listening to music was associated with 6% of the crashes reported by the teenagers and 9% of the crashes reported by the adult 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 crashes were related to being busy or distracted by factors other than those specifically mentioned in *Table 1.6*. The results concerning various circumstances preceding or accompanying crashes should, however, be treated with caution due to the small number of crashes reported by our respondents.

Table 1.6. Specific circumstances preceding or accompanying the crash per age group.

	% of crashes		
Circumstance	**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%

1.3.12. Impact of listening to music and talking on the phone on crashes and noise-related incidents.

As mentioned in *Section 1.3.11* just over 6% of the respondents reported having been involved in a bicycle crash. This low percentage did not allow for further statistical analysis. Therefore, the frequency of getting startled or surprised ('Incidents') was chosen as an alternative indicator of cycling safety in the AMOS path analysis. Getting startled or 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 expectations and poor hazard anticipation (e.g. Kinnear et al., 2013) – concepts which have shown to be important for traffic safety. As the data were non-normally distributed, maximum-likelihood (ML) estimation in AMOS was used with bootstrapping (1000 boot- straps were performed). When the hypothesized model shown in *Figure 1.1* was tested on the calibration sample, this resulted in an 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 adult 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 the calibration data also fitted the validation data. We therefore only present the results of the path analysis for the teenage cyclists. *Table 1.7* presents the goodness-of-fit indices for the final solution for the calibration and the validation sample for this age group.

Table 1.7. Goodness-of-fit indices of the model for the calibration (*N*=374) and validation (=374) and the whole sample for teenage cyclists (*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 1.6 shows the final model for the complete sample of teenage cyclists. Cycling exposure was not related to any other endogenous variable and was therefore removed from the model. The variables *Complex situations*, *Sensation seeking* and *Risk perception* explained 23% of the total variance in *Phone conversation*, 12% of the total variance in *Listening to music* and 10% of the total variance in *Risky behaviour* (risky behaviour other than listening to music or talking on the phone). 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 *Risky behaviour* (0.29). *Sensation seeking* is related to listening to music, *Phone conversation* 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 in 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, on the other hand, a positive relationship between *Risk perception* and *Risky cycling behaviour* indicating that the higher risk perception of cyclists was, the more frequently cyclists engaged in risky cycling behaviour. *Figure 1.6* shows also that there is a positive relationship between *Phone conversation and Listening* *to music*. These two activities were also related to other *Risky cycling behaviour*.

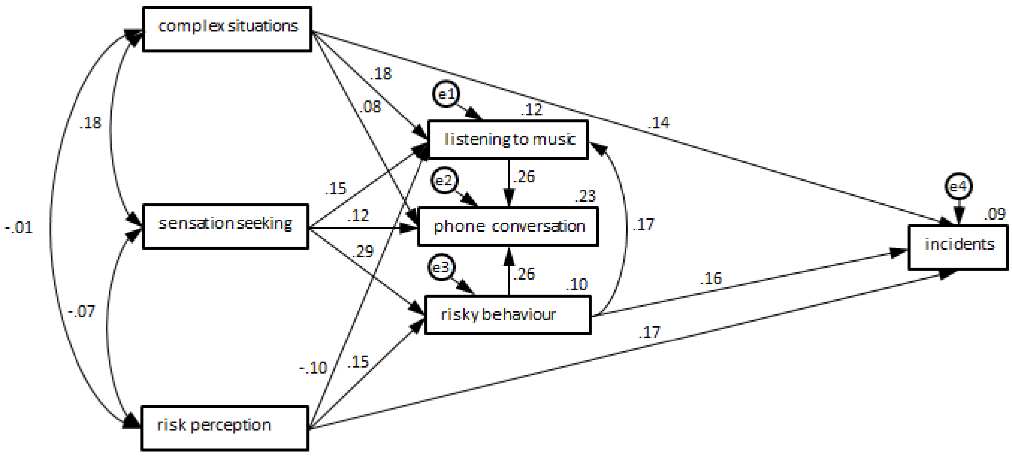

Figure 1.6. The final model; e1 to e4 represent error terms (residual variances within variables not accounted for by pathways hypothesized in the model).

Finally, we can see that 9% of the total variance in 'Incidents' is explained by a direct effect (0.14) of *Complex situation* as well as by both an indirect very small effect mediated via *Risky behaviour* (0.15 * 0.16 = 0.02) and a direct effect (0.17) 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.

1.4. Discussion

The use of auditory cues has become more challenging for cyclists due to listening to music or conversing on the phone while cycling but also due to the quietness of slow-moving electric cars. Given the widespread use of mobile phones, and more recently smartphones by younger cyclists, and ambitious deployment targets for electric cars in many countries, it is increasingly important to examine the relationship between limited auditory information and cycling safety. To achieve a better understanding of this relationship, the present study examined auditory perception, compensatory behaviour and involvement in crashes and incidents among cyclists in three age groups.

1.4.1. Age differences

The greatest age differences were generally found between the oldest respondents and the other two age groups. The differences between teenagers and adult respondents were often less pronounced. In line with previous studies, we found that both listening to music and talking on the phone are much more popular among teenage cyclists than among older age groups. Only a small percentage of cyclists in the oldest age group reported that they (rarely) engaged in these activities. Although older cyclists generally seldom listen to music or talk on the phone, a higher percentage of them reported getting startled or surprised more than once by other road users compared to the two younger age groups. A decline in hearing acuity with advancing age (e.g. Schieber & Baldwin, 1996), also observed in our sample, could explain this finding. Older cyclists may have had problems with auditory detection and localisation of other road users. Previous research found that the elderly are less accurate at auditory detection and localisation of moving cars than younger adults (Mendonça et al., 2013; Stelling-Kończak et al., 2016). It is important that future studies address the issue of older cyclists' not being able to hear other road users. Furthermore, a higher percentage of older cyclists reported getting surprised or startled by a (light) moped rider compared to teenage and adult cyclists. Possibly, these differences may originate from speed differences between older cyclists and (light) moped riders. (Light) moped riders ride on average faster than cyclists (Schepers, 2010); and older cyclists cycle on average at lower speeds than younger cyclists (Schleinitz et al., 2017; Vlakveld et al., 2015). As a result light moped riders possibly overtake older cyclists more frequently and with a higher speed difference causing older cyclists, who generally have poorer hearing, to startle more often than younger cyclists. Except for hearing problems, other functional limitation which accompany ageing, such as declines in visual functions, fluid intelligence, speed of processing, working memory and motor functions (see e.g. Davidse, 2007), may also explain the age differences found in this study. Research shows that older cyclists experience difficulties at the operational level (indicating direction with the left hand and looking over the shoulder). Older cyclists were also found to have lower grip strength scores, a higher mental workload and longer reaction times while cycling and to perform more corrections to stabilize a bicycle than middle-aged cyclists (Kovácsová et al., 2016; Vlakveld et al., 2015). These functional limitations do not necessarily have to lead to unsafe traffic situations, since older road users can consciously or unconsciously compensate for the limitations. Older drivers, for example, often choose to drive during daytime and dry weather (Smiley, 2004). There are various factors which may facilitate compensatory behaviour among older road users: they have more freedom to choose when to travel, they generally have more experience in traffic (which can help them to anticipate possible hazards) and the desire for sensation and excitement decreases with age (older road users are for example more inclined to obey the rules). Little is known about compensatory behaviour of older cyclists. However, it has been argued that the ability of older road users to compensate is possible only up to a certain point at which the functional limitations begin to outweigh the advantages related to experience and cautious behaviour. As a consequence of not being able to fully compensate for their functional limitations, paired with the age-related increase in physical fragility, the crash risk of older road users begins to increase (see also Davidse, 2007; Holland, 2001).

1.4.2. Auditory perception of cyclists

The present study shows also that listening to music and talking on the phone negatively affect the perception of sounds crucial for safe cycling. Cyclists reported that they could hear less sound when listening to music or talking on the phone than is necessary for safe cycling. Listening to music was found to have more impact on auditory perception than talking on the phone. Our findings confirm the results of a previous field study showing that cyclists more often miss important auditory information when listening to music than when talking on the phone (De Waard, Edlinger & Brookhuis, 2011). In the introduction we provided two potential explanations for the negative effects of music and telephone conversation on auditory perception: auditory masking and distraction. A recent fundamental study into auditory localisation of critical environmental sounds suggests that the negative effects of music and telephone conversation could be attributed to masking effects rather than to the effects of distraction (May & Walker, 2017). May and Walker have found that auditory localisation was not affected by whether listeners ignored or attended to distractors. Furthermore listening to music with lyrics was more detrimental than speech for auditory localisation of across almost all sounds (including the broad- band white and pink noise); this is probably due to the greater range of frequencies of the masking sound present in music with lyrics. Auditory information can act as an attentional trigger and can facilitate detection and localisation of other road users. Not being able to hear relevant traffic sounds can have serious consequences for cyclists, especially in situations where cyclists rely on auditory information, e.g. due to visibility obstruction or visual distraction. If the limited auditory input is not compensated for by, for example, the increase in visual attention, the safety of cyclists is likely to be compromised.

1.4.3. Compensatory behaviour while listening to music and talking on the phone

In line with previous studies using self-reported data, the majority of cyclists who listen to music or talk on the phone were found to use compensatory strategies. Compensatory behaviour was reported by about two-thirds of the teenage respondents in the present study. The most often mentioned compensatory strategy for listening to music was turning the music down or off when necessary, looking around more frequently or using one earbud instead of two. Decreasing speed, keeping conversations short and looking around were the most often reported compensatory strategies for talking on the phone. The results are in line with the Internet survey by Goldenbeld et al. (2012) and partly in line with the recent findings of the studies in real traffic (Ahlstrom et al., 2016; Kircher et al., 2015). Reducing speed has generally positive effects on traffic safety. However, too low speeds can pose a safety risk (lower than about 14 km/h) requiring the cyclist to put more effort in stabilizing the bicycle (see e.g. Schwab, Meijaard & Kooijman, 2012), and causing decrements in lateral control. In contrast to texting, listening to music and talking on the phone has neither been found to affect cyclists' average lateral position nor the variation in lateral position (De Waard et al., 2010).

The findings concerning visual behaviour of cyclists found in our study and other surveys appear inconsistent with the results of on-road studies. Specifically, the increase in visual behaviour reported by cyclists in survey studies is not found in on-road research in which cyclists' visual behaviour whilst listening to music was similar to the visual behaviour while 'just' cycling (Ahlstrom et al., 2016; Stelling-Kończak et al., 2018). As for talking on the phone, cyclists who engaged in this activity were in the study of Ahlstrom et al. found to use visual strategies: they decreased their glances towards traffic-irrelevant targets and shortened glance durations to traffic relevant targets, while maintaining the number of glances. The inconsistency concerning compensatory behaviour between the results of surveys and on-road studies could also be due to the difference in the studied traffic environment. Contrary to the field studies, the surveys did not concern specific, relatively undemanding traffic environments, leaving open the possibility that cyclists who listen to music or talk on the phone do increase their visual attention only in some, for example more demanding, traffic situations. Finally, surveys generally rely on what people think they do rather than their actual behaviour. Road users, and human beings in general, tend to overestimate their (driving) skills (see e.g. De Craen et al., 2011; Taylor & Brown, 1988). This phenomenon has recently also been found in a study among cyclists (Kovácsová et al., 2016).

1.4.4. Involvement in crashes and incidents

Finally the present study investigated the extent to which listening to music and talking on the phone impact the safety of cyclists. As crashes are rare events, incidents were used as an alternative indicator of cycling safety. Taking into account the influence of confounding variables, no relationship was found between the frequency of listening to music or talking on the phone and the frequency of incidents among teenage cyclists. This may be due to cyclists' compensating for the use of portable devices, as mentioned before. Another explanation for the lack of the relationship between listening to music or talking on the phone and incidents might be behavioural adaptation of other road users who encounter a cyclist using electronic devices. Car drivers might, 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 (for examples of behavioural adaptation in traffic see Rudin-Brown & Jamson, 2013). This explanation seems less probable since it may not be easy for car drivers to detect whether a cyclist is using electronic devices. Our results show for example that only about 5% of cyclists who listen to music use headphones – the majority of cyclists use one or both earbuds which are hardly visible from a distance. Furthermore, although both listening to music and talking on the phone have been found to affect cycling behaviour, the changes in cycling behaviour may not be directly observable for car drivers. Specifically, talking on the phone while cycling has been related to a decrease in speed and an increase in reaction time as well as in the number of unsafe behaviours. Cyclists who listen to music have also been observed to engage in unsafe behaviours. Additionally, these cyclists have been found to disobey traffic rules more frequently than those who 'just' cycle (see Stelling-Kończak, Hagenzieker & Van Wee, 2015). The present study also found that cyclists in all age groups got startled or surprised mainly by car drivers and other cyclists. This finding may not be surprising as these are the road users that cyclists in the Netherlands are most likely to encounter. On the other hand, cyclists are 'silent' road users who can presumably be more easily missed than 'noisy' cars.

Finally, the frequency of getting involved in an incident was found to be positively related to cycling in complex situations, risk perception and risk cycling behaviour. Listening to music and talking on the phone was not related to incidents but it was positively related to other risk cycling behaviour. These findings underline the importance of taking into account the influence of confounding variables, such as cycling in complex traffic situations and other risk behaviour when estimating the impact of secondary tasks on cycling safety. Listening to music and talking on the phone apparently co-occur with other risk behaviour.

1.4.5. Implications

Although the results of this study show that listening to music or talking on the phone does not impact cycling safety measured by incidents, we cannot conclude that engaging in these activities whilst cycling is without risk. The effect of performing such secondary tasks on cycling safety is likely to depend on the traffic environment and on the cyclist's compensatory strategies (see the model in *Figure 1.1*). Listening to music or talking on the phone while cycling may still pose a safety threat in the absence of compensatory behaviour or a traffic environment with less extensive and less safe cycling infrastructure than the Dutch setting.

Given the popularity of listening to music among teenage cyclists, we may need countermeasures that discourage listening to music whilst cycling. Some countries (Germany, New Zealand, a few states in the USA) have already banned cyclists from wearing headphones while on the road. In the Netherlands, as well as many other countries, it is not forbidden for cyclists to listen to music. However, by reason of a general law in these countries listening to music while cycling can be fined if it results in hazardous behaviour (Meesmann, Boets & Tant, 2009). Education and public information can raise cyclists' awareness of the dangers associated with listening to music while on the road. Recently, specifying implementation intentions ("if-then" plans) have been found effective in encouraging safer driving behaviour, i.e. speeding behaviour (see Brewster, Elliott & Kelly, 2015). This new type of intervention may also have the potential to break the habit of listening to music while cycling. Other solutions seem promising in mitigation of the negative effects of listening to music while cycling. Listening to music at low volume, using one earphone instead of two or using music devices with a built-in microphone allowing for simultaneous music and surrounding sounds playback may allow cyclists to utilize auditory cues from the traffic environment. However, further research into the safety effects of these solutions is needed before they can be recommended.

The rising number of electric cars may also have impact on the safety of cyclists in general and those who listen to music or talk on the phone. Many countries, including the Netherlands, aim at increasing the number of those cars considerably. The majority of the cyclists in this study indicated that they never or seldom encountered quiet (electric) cars when cycling. This is in line with Dutch statistics showing that only about 2% of the total number of cars in the Netherlands is electric or hybrid[4] With the increasing number of quiet (electric or hybrid) cars, cyclists in general and those who listen to music and talk on the phone will encounter electric cars more frequently in the future. The frequency of incidents caused by failing to hear these cars may increase, especially during transition periods where cyclists will have to cope with a mix of vehicles having various acoustic properties.

1.4.6. Limitations

One of the limitations of this study is the use of subjective assessments, which can have important disadvantages (social desirability, possible non-accurate recall, or selective non-response bias). Care was taken to limit these disadvantages. Our Internet survey guaranteed anonymity and the topic of the survey was quite neutral: listening to music and talking on the phone are not illegal in the Netherlands, which may encourage respondents to be honest in their answers. To enhance accurate recall, cyclists were asked to report recent incidents − incidents taking place in the past month. Cyclists spent a few hours a week on cycling, thus the topic of the survey concerned a familiar activity. Pre-testing confirmed that the questionnaire was clear and readable. However, some bias cannot be excluded. Most traffic behaviours are automatic and therefore not consciously monitored. They may not be easily recalled. Cyclists may for example not be consciously aware of specific encounters with electric cars or of what they can and cannot hear while cycling. Another limitation regards the correlational design of the present study, since correlation does not imply causation. Generally causal effects cannot be proven unless variables have experimentally been manipulated.

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[4] At the time of data collection (in 2014) 1.7% of the total number of cars in the Netherlands was electric or hybrid; currently (2016) 2.6% of cars are electric or hybrid (BOVAG/RAI, 2016).

1.4.7. Concluding Remarks

In this study both listening to music and talking on the phone was found to diminish cyclists' auditory perception. However, engaging in these activities was not found to negatively impact cyclists' involvement in incidents. This could be due to the use of compensatory strategies by cyclists. The majority of cyclists who reported listening to music or talking on the phone also reported using compensatory strategies. Listening to music or talking on the phone without compensatory strategies may still pose a safety threat. This study shows furthermore that the majority of the cyclists never or seldom encountered quiet (electric) cars on the road. However, as the number of electric and hybrid cars is increasing, the question arises 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 these cars in the future.

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