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ORIGINAL ARTICLE

Bicyclists' adaptation strategies when interacting with text messages in urban environments

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Abstract
Cyclists' use of mobile phones in traffic has typically been studied in controlled experiments. How cyclists adapt their behaviour when they are not limited to a certain set of behaviours has not been investigated to any large extent. The aims of this study are to explore how cyclists adapt when texting and listening to music in a complex urban environment, and if they compensate sufficiently to maintain safe traffic behaviour. Forty-one cyclists participated in a semi-controlled study, using their own bike and smartphone in real traffic. They were equipped with eye tracking glasses and travelled two laps completing a total of 6 km divided into six segments. For one of the laps, the cyclists were requested to listen to music. On three occasions, they received a text message to their phone, which they were supposed to handle as they normally would when cycling. Static minimum required attention measures were used to examine the influence on attention. The results show that listening to music while cycling did not affect workload, speed, SMS interaction or attention. Seven different adaptation behaviours were identified when the cyclists dealt with received text messages. One-fourth of the text messages were replied to while cycling. In general, the cyclists manage to integrate SMS interactions with their cycling behaviour. Nevertheless, there were two occasions when basic attention criteria were violated while texting, which motivate further studies.

Keywords Mobile phone · Bicyclist · Attention · Behavioural adaptation · Text message · Music

1 Introduction

Cyclists, just as drivers and pedestrians, often use their mobile phones in traffic. Much research has been devoted to understanding the consequences of mobile phone interactions in car driving, showing deteriorated control of the vehicle (Caird et al. 2008, 2014; Collet et al. 2010; Horrey and Wickens 2006; Kircher et al. 2011; Nabatilan et al. 2012; Svenson and Patten 2005), but also driver adaptation strategies to counteract the consequences thereof. Car drivers often initiate visual or manual tasks, such as texting, while driving at lower speeds (Funkhouser and Sayer 2012; Tivesten and Dozza 2015) or when stopped, e.g. at a red traffic light (Funkhouser and Sayer 2012; Huth et al. 2015; Kidd et al. 2016). When engaged in a cell phone conversation, they change lanes less frequently in high-density traffic (Cooper et al. 2009; Fitch et al. 2014) and spend more time behind a lead vehicle (Cooper et al. 2009). Drivers frequently adapt their involvement with self-paced additional tasks to the current requirements in traffic (Eriksson et al. 2014; Kidd et al. 2016; Metz et al. 2014, 2015; Platten et al. 2014; Schömig et al. 2011). Less research has been made on cyclists and their mobile phone use.

The prevalence of mobile phone use while cycling has been reported to be in the range of 3–30%, much depending on whether listening to music was counted as phone use or not. In the Netherlands, the prevalence was found to be about 3% in 2013, where talking on the phone constituted .7% and screen operation constituted 2.3% (de Waard et al.

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2015). In Vietnam, the prevalence of phone use while riding e-bikes was found to be 4.4% in 2015, with 2.4% talking and 2.1% screen operation (Truong et al. 2016). In Sweden, the prevalence was 19% in 2012, with 17.1% listening to music, 1.9% calling and .6% interacting with the phone (Adell et al. 2014). In Boston, MA, USA, 31.2% of the observed bicyclists used their phones, where 17.7% used earbuds or talked on the phone and 13.5% interacted with their phones (Wolfe et al. 2016). How phone use corresponds to crash risk is less known. An internet survey in the Netherlands estimated that the odds of being involved in a bicycle crash are higher for teen cyclists (factor 1.6) and young adult cyclists (factor 1.8) who use electronic devices on every trip compared to cyclists who never use these devices (Goldenbeld et al. 2012). However, for the middle-aged and older adult cyclists, the use of portable devices while cycling was not a significant predictor of crash involvement. In an Italian questionnaire study, it was found that smartphone use predicted crashes through their consecutive effects on cycling errors and near crashes (Puchades et al. 2017). Alongside crash statistics, it is important to investigate behavioural changes to get the fuller picture of how mobile phone use while cycling affects traffic safety.

Controlled experiments have shown that in general, mobile phone use while cycling is associated with reduced speed, reduced peripheral vision performance, increased mental effort ratings and reduced lateral control (de Waard et al. 2010, 2011, 2014). The effects are larger when handling the phone, such as when writing a text message, and especially so when using a touch screen (de Waard et al. 2014). When it comes to listening to music with earbuds while cycling, only limited effects on bicyclists' behaviour have been found (de Waard et al. 2011, 2014; Kircher et al. 2015), except for worsened auditory perception (de Waard et al. 2011, 2014). A limitation with most of these studies is that the participants were not allowed to choose how to integrate the mobile phone task with the cycling task. For example, the cyclists claim that they look around more frequently when using their mobile phone, that they do not use their devices in demanding situations and that they sometimes use one earbud instead of two (Goldenbeld et al. 2012; Stelling-Konczak et al. 2017). Despite these self-reported claims, observational studies report that cyclists who use their phones make fewer head movements to the right than cyclists who were only cycling (de Waard et al. 2015). Such discrepancies motivate more detailed studies on cyclist behaviour in naturalistic settings. Kircher et al. (2015) and Ahlstrom et al. (2016) therefore conducted experiments in a semi-controlled setting where the experimenters defined the route and the tasks, whereas the participants could choose when and where to perform the tasks. The results showed that cyclists did indeed use a variety of compensation strategies to incorporate the investigated secondary tasks (phoning, texting and browsing) with the cycling task. Some cyclists stopped cycling when performing the tasks, others reduced their speed, many postponed the task to an appropriate time and place along the route, and most of them scanned the surroundings prior to commencing the task. The results also showed that all cyclists managed to successfully integrate the mobile phone tasks with the cycling task. Even though the study was conducted in real traffic, the traffic environment consisted of a separated cycle path with a low traffic volume, so that there were few interactions with other road users. Also on the streets intersecting the cycle path, traffic volumes were low. Stelling-Konczak et al. (2018) investigated visual behaviour amongst teenage cyclists when listening to music on a route from their home to school. They found no significant changes in visual behaviour when listening to music and concluded that the teenagers did not adapt to the music task by increased visual scanning, as claimed by other cyclists in self-reports.

Michon (1985) describes three levels of the road user task, i.e. the strategic level in which general plans of a trip are made, the tactical level in which manoeuvre control is applied based on the current situation, and the operational level in which automatic action patterns apply. Allowing the participants in a study to choose when and where to execute the tasks of interest has the advantage that adaptive and compensatory behaviour on the tactical level can be studied. Disadvantages are decreased experimental control and more complicated analyses (Kircher et al. 2017a). In a semi-controlled study, the posed research questions are allowed to move from the operational level to the tactical level, but when doing so, it is important to also adapt the corresponding performance indicators to this type of experimental setting. For example, performance indicators of inappropriate behaviours that are commonly used in controlled studies, such as long glance durations away from the road or large swerving but within the lane boundaries, tend to lose their meaning if these behaviours only occur in areas with no traffic, where it is supposedly safer to look away for a longer time period [due to the abilities of peripheral vision when it comes to tracking and lane keeping (Wolfe et al. 2017)]. How to choose appropriate performance indicators in a semi-controlled study is not trivial. One way is to define situational demands that the participant has to fulfil. The number of demands that are not fulfilled can then be compared between baseline and treatment, to see if, for example, texting or listening to music while cycling is detrimental for safety. In this study, we adopt the minimum required attention (MiRA) theory (Kircher and Ahlstrom 2017) to set up these demands (or requirements). MiRA defines what a road user needs to be attentive to, and also when, where and how frequently information needs to be sampled from these required targets. Only static MiRA requirements related to the infrastructure (such as checking that the side roads are clear before entering an intersection and checking traffic lights) are used in this study. Despite the obvious disadvantages of not accounting for the dynamics of moving traffic, an actual merit of this is that it allows more fair comparisons between baseline and treatment despite possibly different traffic situations in the two conditions.

So far, the behaviour of cyclists interacting with their mobile phones in their own way in real traffic environments has not been extensively studied. There are indications that cyclists employ adaptation strategies to successfully interact with their mobile phones in simple settings, but if that applies in more difficult situations is not clear. The aims of this study are thus to investigate how cyclists adapt when texting and listening to music in a complex urban environment, and if they compensate enough to uphold a safe behaviour with respect to themselves and other road users. At the time of the study (2016), there were no specific laws prohibiting mobile phone use while driving or cycling in Sweden. However, the Swedish legal framework clearly states that it is only allowed to use communication devices while driving a motorized vehicle if it does not have a negative impact on driving safety (The Swedish Police 2017; The Swedish Transport Agency 2017). This is an amendment to the general law against reckless driving (Government Offices of Sweden 2015), which covers texting, listening to music and many other behaviours. The law against reckless driving applies to all road users, including pedestrians and cyclists.

2 Method

A semi-controlled study in real traffic with a mixed design was used in the city of Linköping, Sweden. Each participant rode the same route twice, once while listening to music and once without music. The route was divided into a total of six segments, three per lap, and on one of these segments on each lap, the participant was asked to think aloud about his or her distribution of attention. Each participant also received three text messages along the route which they were instructed to deal with as they normally handle incoming text messages while cycling.

2.1 Participants

Participants were recruited via an on-line questionnaire, which was advertised in social media like Facebook, and through local bike clubs, flyers and e-mails to companies in the area. In total, 533 persons stated that they were willing to participate in the study, and 342 persons fulfilled the inclusion criteria: > 18 years old, experienced with cycling in the city centre of Linköping, willing and able to cycle for 6 km, provide own bike and smartphone, used to using the phone in traffic, and normal eyesight or eyesight that could be corrected with contact lenses or with extra dioptric lenses within ± 4 dioptres, which was a requirement to be able to use the eye tracking system. Both normal bikes and e-bikes were allowed. Participants were recruited for the study primarily with the aim to achieve an equal number of cyclists self-evaluating their cycling speed as slower than others, equal to others and faster than others. The first cyclists fulfilling the criteria were contacted for participation in the study. When asked about familiarity with cycling in the city centre of Linköping, about one-third (32%) of the participants cycled there daily, while one-third (27%) cycled 2–4 times a week and one-third (32%) at least twice a month. 10% cycled more seldom in the city centre. Results regarding cyclists' speed and delays at specific traffic sites for different self-evaluated speeds are reported by Kircher et al. (2018). The study was approved by the regional ethical review board in Linköping (Dnr 2016/174-31).

2.2 Design and procedure

The route chosen for cycling was situated in the city centre of Linköping and was 3 km long. The traffic environment consisted of cycle tracks, mixed traffic as well as pedestrian streets without motorized traffic. Segment 1 (A–B in Fig. 1) consisted of a separated cycle lane ending with a round-about with mixed traffic. The speed limit was 30 km/h turning to 40 km/h at the intersection half-way through the segment. Segment 2 (B–C) was to a large extent comprised of mixed traffic, including a round-about and a stop sign, turning into a cycle path and ending with a road stretch within a pedestrian zone. Except for the round-about, which had a prescribed speed limit of 40 km/h, the speed limit was 30 km/h throughout this segment. Segment 3 (C–A) started with a cycle path that turned into a cycle and pedestrian path, followed by a road stretch with mixed traffic, a short cycle and pedestrian path, and ending with a road stretch with mixed traffic. The speed limit in segment 3 was 30 km/h, but on the first mixed traffic part a lower speed of 20 km/h was recommended by signage.

Each participant brought his or her bike and telephone to the starting point. While one researcher equipped the handlebars of the participant's bike with two cameras (GoPro Hero 3, one forward facing and one facing the cyclist), another researcher informed the participant about the study, asked the participant to sign an informed consent form, and fitted and calibrated the eye tracker (SMI 2.0, SensoMotoric Instruments, Teltow, Germany). A third researcher, "the follower", followed the participant during the experiment with a GoPro Hero4 camera facing forward on his bike recording the participant and the road environment. The follower greeted the participant and asked the participant to ignore being followed. The follower's task was to ride behind the participant at a distance of 10–15 m,

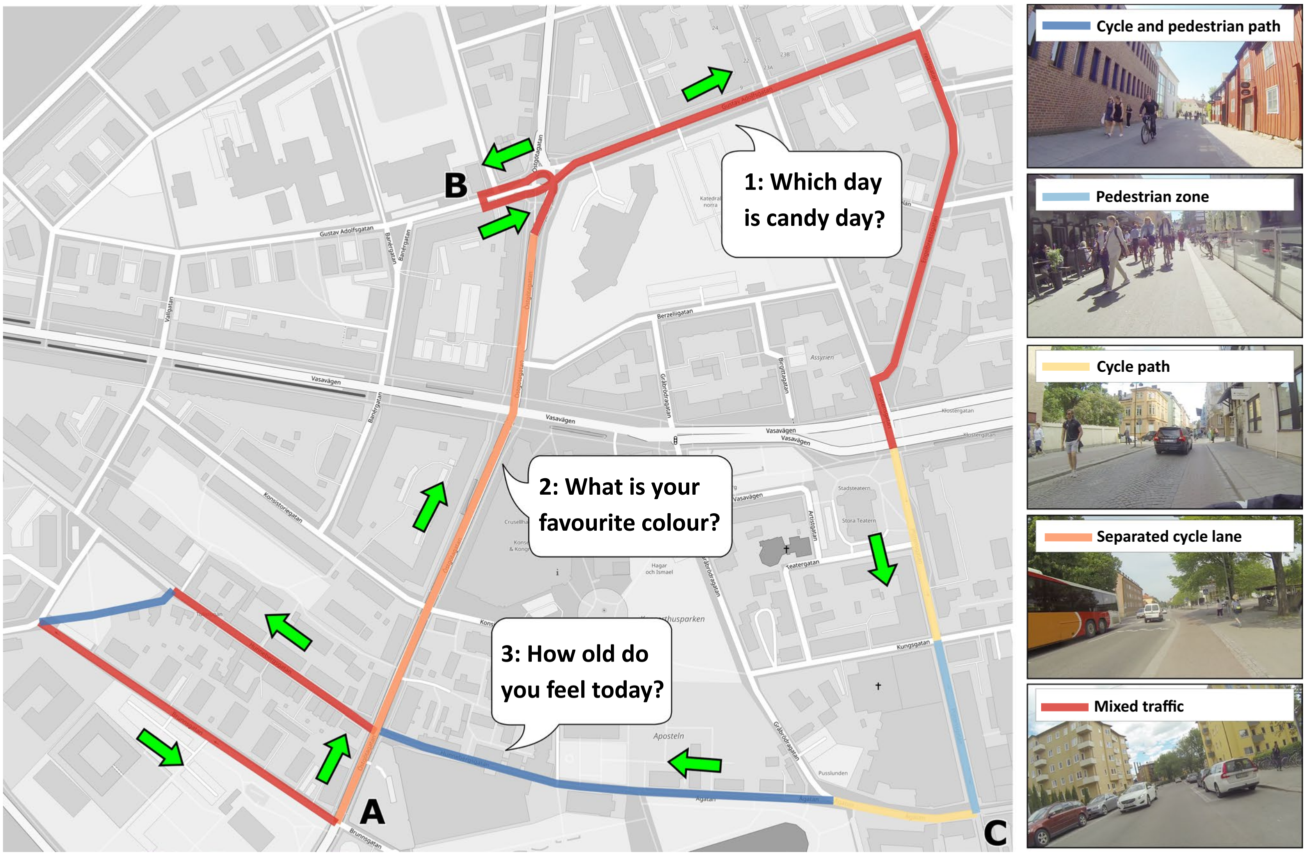

Fig. 1 Segment 1 cycled was from A to B, segment 2 was from B to C, and segment 3 was from C to A. “Candy day” is a well-known concept in Sweden, with the aim that children should only eat candy once a week, on Saturday, for dental health reasons. Map source: OpenStreetMap contributors (2017)

filming an overview of the situation, and to notify the participant, in case that he or she took a wrong turn.

Before setting off, the participant was informed whether or not to think aloud on the upcoming segment and whether or not to listen to music on the first or second lap. It was stressed that the participant moved in real traffic and that he or she should behave as they would on a typical ride, as the aim of the study was to capture the cyclists’ natural behaviour.

Think-aloud verbal protocols contain participants articulating their thoughts while performing a task, and it gives access to information currently in the participants’ short-term memory (Ericsson and Fox 2011; Ericsson and Simon 1980). On the think-aloud segments, the cyclists were asked to verbalize what they were thinking of, primarily in terms of where they directed their attention, what caught their attention and how they scanned the traffic and the surroundings. Since it is known that think aloud affects visual behaviour, with longer glances to objects that are currently being described (Hertzum et al. 2009), the participants were only required to think aloud on two out of six segments (balanced between participants).

In the music condition, the participants used headphones connected to their smartphone and could determine volume, tempo, how many earbuds they would use and what they would listen to, e.g. music, radio or podcast. Throughout this article, this will be referred to as listening to music, or as the music condition, even though other self-chosen media are included.

The participant then cycled along the route at his or her preferred speed, followed by the follower. At each end point of a segment, a researcher met up with the participant, asked whether anything special had occurred during the segment, asked the participant to fill in a NASA-RTLX (a subjective, multidimensional assessment tool that rates perceived workload in terms of mental demand, physical demand, time pressure, performance, effort and frustration, Hart and Staveland 1988) for the segment just cycled, explained the route for the next segment, and informed the participant whether to think aloud or not on the upcoming segment. When the participant returned to the starting point after two laps, the logging equipment was removed, and the follower asked the participants about two or three occurrences along the route. These were selected freely by the follower, based on what had happened while cycling (for example, cycling on the pavement). The answers to these questions are not investigated here (see instead Kircher et al. 2017b).

Each participant received three text messages when cycling. The text messages were sent by an experiment leader tracking the position of the cyclist via GPS. For practical reasons, the order and content of the messages was the same for all participants (see Fig. 1). The first message was sent on lap 1, segment 2, on a straight road stretch in mixed traffic along parked cars, just before arriving at an intersection with a stop sign. The second message was sent on lap 2, segment 1, on a separated cycle lane, before arriving to a larger intersection. The third message was sent on lap 2, segment 3, on a cycle and pedestrian path where no motorized traffic was allowed. The questions in the messages were chosen so that not too much effort should be required to answer them, neither mentally nor manually. The participants were not informed about where, when or how many text messages they would receive, only that they would receive text messages and that they were supposed to handle them as they normally would when cycling and receiving text messages.

2.3 Data reduction

For each participant, a GPS track, gaze direction, and videos of the forward view, of the cyclist's face and from behind from the follower's bike were logged. In addition, workload as measured by the NASA-RTLX was collected for each of the six segments, and answers to questions about incidents/events in traffic were noted. The data were annotated using the Observer XT 13.0 (Noldus Information Technology, Wageningen, the Netherlands), by manually marking gaze directions, complexity level and attentional demands. Each cyclist's natural speed was calculated for road stretches without intersections, hills or slopes and where there was no other traffic. Due to poor GPS tracking accuracy in the city, this was done using cues in the traffic environment for start and stop of the distance, and the total time that the cyclist used cycling the distance.

The eye tracking data were manually encoded as glances towards the forward area, towards the phone and towards other gaze targets. Given the importance of peripheral vision in traffic, a breakdown into smaller target regions did not appear meaningful. Complexity levels, estimating roughly for how long it would be possible to close one's eyes or to look away from the road without missing important information, were determined based on the videos, according to Table 1. For each instance where the cyclists interacted with their phone when cycling, the complexity level was coded in retrospect from the videos, continuously and subjectively by the authors. Note that the complexity rating scale has not been validated and that the threshold values are based on the authors' previous experience.

The attentional requirements along the route were defined according to the minimum required attention theory (Kircher and Ahlstrom 2017). This was done by defining all static objects the participant had to attend to in order to be able to navigate the route safely. Examples include looking left and right in intersections, and looking at stop signs and traffic lights. In addition to such *necessary* requirements, we also encoded *useful for own safety* requirements, such as looking over the shoulder before crossing a street even though the cyclist had priority. Figure 2 gives an example of static MiRA requirements in an intersection. For all SMS events where the bicycle was moving, including their matched baselines (identical location but on the other lap), and for three intersections (one lap with and one without music), it was determined whether the MiRA requirements were fulfilled. The intersections were all four-legged intersections where the cyclist route continued straight through, but where different rules applied.

Intersection 1 The cyclist travelled on a separated cycle path on the approach, passed an intersecting cycle path and then reached the intersection where there was a traffic light for cars and a separate traffic light for bicycles (see also the sketch in Fig. 2).

Intersection 2 The cyclist travelled in mixed traffic and encountered a stop sign on the route, whereas the intersecting road was the main road.

Intersection 3 On approach, the cyclist travelled on a cycle lane in the roadway and had the right of way.

Three categories were used for deciding whether a MiRA requirement had been fulfilled: *attended* (based on the verbal protocol, eye tracking, or as assumed by behaviour), *probably not attended*, or *impossible to decide*. Impossible to

Table 1 Categorization of complexity levels

Complexity level	Time possible to close eyes or look away from road	Example situation
0	> 3 s	Separated wide cycle path with no surrounding road users
1	1–3 s	Cycling at normal speed on cycle path with obstacles far away
2	< 1 s	Cycling with obstacles to avoid, such as pedestrians
3	Not possible	Overtaking, while approaching the overtaken object

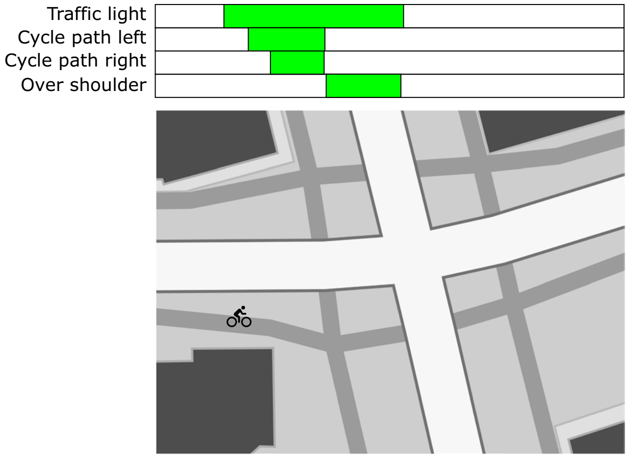

Fig. 2 Example of static MiRA requirements in one intersection located on the experimental route. The intersection consists of two four-lane roads (white) flanked by cycle paths (grey) and pavements. The dark grey structures in the corners are buildings blocking the view from the cyclist's perspective. The green area above the map corresponds to the road stretch within which the cyclist should attend to the respective requirements. Map source: OpenStreetMap contributors (2017) (color figure online)

decide could, for example, occur in cases where eye tracking was missing. In this study, only requirements related to static objects in the traffic scene were used. Ideally, also dynamically changing objects, such as surrounding road users, should be included amongst the requirements. However, the spatial resolution of the eye tracker, along with the difficulty of accounting for peripheral vision, prevented such analyses in the present study.

2.4 Analyses

Analyses of variance, using participant as a random factor, were used. The significance level was set to .05.

For text messages, the data from picking up the phone until putting it back again were analysed. In cases where a text message is read and answered with a delay in-between, the data in-between were excluded from the data material.

3 Results

Forty-one participants (37.4 ± 11.1 years old, 46% women) participated in the study. Two participants (5%) used only one ear bud, and the remaining participants used two earbuds. There was no significant difference in workload between when the cyclists listened to music (2.12 ± 1.12) and when they did not listen (1.97 ± 1.28), $t(40) = -.895$, $p > .05$. The workload measures varied on low levels, and the participants estimated their load (mental, physical, time pressure, frustration and effort) as small and their performance as good in both conditions. There was no difference in speed when the cyclists listened to music (20.40 ± 4.22 km/h) and when they did not listen (20.90 ± 4.63 km/h), $t(40) = -1.11$, $p > .05$. For the three MiRA coded intersections, 82% of the necessary MiRA requirements were attended to in the music condition and 86% without music. This difference was not significant ($F(1, 412) = .96$, $p > .05$). The corresponding percentages for the useful MIRA measures were both 76% ($F(1, 251) = .004$, $p > .05$).

Out of a total of 123 text messages sent to the participants, at least two messages were delayed and not received until after the test. When we asked the participants after completing the test to state how many of our text messages they heard, 47.5% stated that they heard all three messages, 25% heard two of them, 22.5% heard one, and 5% did not hear any text message. Not hearing does, however, not infer not replying, because the text message could be noticed by visual or tactical input. Text messages that were not looked at are treated as "ignored or not heard" in the following analysis. Figure 3 shows the SMS interactions in total as well as the distribution of text messages received in the non-music and music conditions for each interaction type. Some messages were answered when the participant met with the experiment leader in connection with answering to the verbal questions after a segment, some participants made a stop dedicated to answering the message, and sometimes texting was made in connection with stopping at a red light. Of the 121 analysed messages, about half were handled on a road segment. Of these, around two-thirds were handled when cycling and most messages were read and answered directly, 23% in total. There was no significant effect of music on the interaction modes to the right in Fig. 3 ($H(1) = 2.24$, $p > .05$).

Since music did not affect workload, attention, speed or SMS interaction, data from listening to music versus not listening to music were merged and will henceforth be analysed together. Pearson's Chi-square test showed no significant association between the location where the text message was received and whether or not the message was handled while cycling ($\chi^2(2) = 3.92$, $p > .05$), see Table 2.

Sorting the participants according to their "most complicated" SMS interaction shown in the study, with the understanding that the interactions to the right in Fig. 3 are ordered from least complicated at the top to most complicated at the bottom, the result in Table 3 was revealed.

The 41 text messages handled while cycling were analysed further. Pairwise t tests (repeated measures) comparing the road stretches where the cyclists texted with the matching road stretches in the baseline condition, showed no significant effects on the time it took to cycle the given segment, see Table 4.

The fulfilment of MiRA requirements was investigated on the road segments where text messages were handled and on the corresponding baseline segments. On

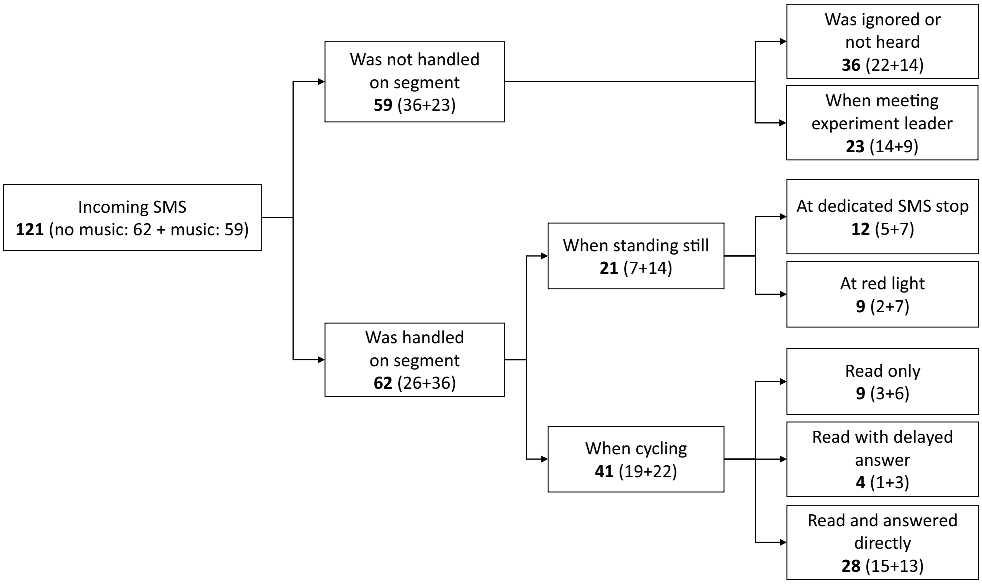

Fig. 3 SMS interactions. Result in total (number of outcomes in the no-music condition + number of outcomes in the music condition)

Table 2 Number of text messages not handled vs handled while cycling in relation to SMS

SMS	Number not handled while cycling	Number handled while cycling
1	29	12
2	30	11
3	21	18

Table 3 Distribution of participants according to their most complicated SMS interaction shown in the study

Most complicated SMS interaction shown	Number of participants
Ignore or do not hear	3
Meeting experiment leader	8
Dedicated SMS stop	4
At red light	6
Read while cycling	4
Read and reply while cycling	16

Table 4 Task completion time for different SMS interactions

SMS interaction type	Mean ± std dev. (s)	*N*	*t*(N−1)	*p*
Read and answered directly	23.3 ± 13.3	28	1.23	> .05
Read with delayed answer	23.8 ± 13.2	4	1.82	> .05
Read only	4.5 ± 6.4	9	− .38	> .05

Table 5 Fulfilment of necessary and useful MiRA requirements while handling text messages compared to the corresponding baseline segments

	Necessary		Useful	
	SMS	Baseline	SMS	Baseline
Left	8/0/1	10/0/0	4/0/0	0/0/2
Right	6/2/1	5/1/0	4/2/3	6/1/3
Right of way rule	1/0/0	1/0/0	NA	NA
Stop rule	3/0/0	3/0/0	NA	NA
Traffic light	8/0/1	10/0/0	NA	NA
Over shoulder	NA	NA	2/0/5	3/1/4
Total	26/2/3	29/1/0	10/2/8	9/2/9

Results are presented as <attended to/impossible to decide/probably not attended to>

NA means not applicable

these road segments, a total of 61 necessary and 40 useful MiRA requirements were investigated. It is relevant to acknowledge that the requirements can differ between SMS and baseline, due to the colour of the traffic light. Table 5 shows that 3 of 31 necessary MiRA measures were probably not attended to while cycling in the texting condition. A closer look at these revealed that the three unattended requirements were all in connection with the traffic light, at two separate instances. At the first instance, the cyclist attended the green light for cars, but was not observed to notice the red light for cyclists and had to negotiate with a car turning right. At the second instance, the cyclist did neither pay attention to an intersecting cycle path to the left nor to the right, when

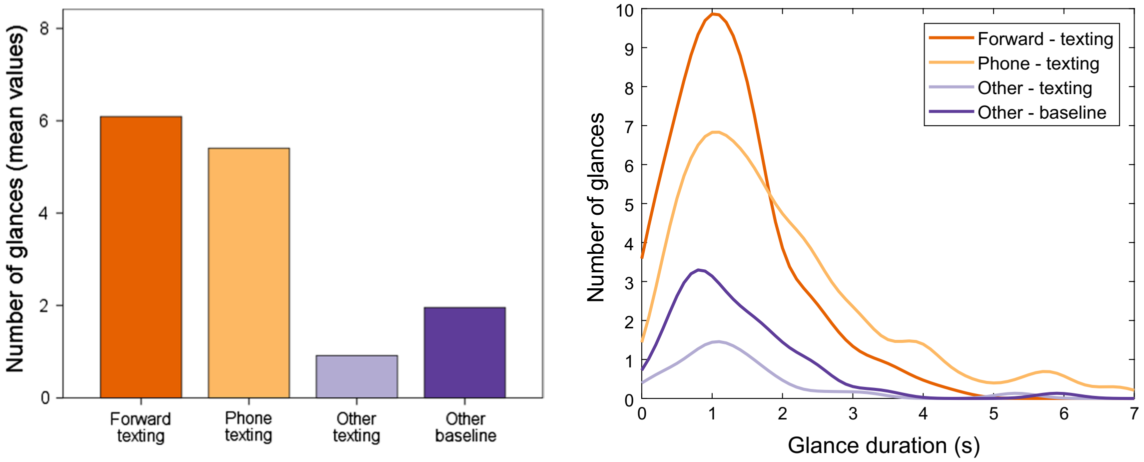

Fig. 4 The number (left) and duration (right) of glances towards the forward area, the phone and other while texting. Glances towards other gaze targets in the matched baseline condition are included in the figure for comparison

approaching the traffic light. The cyclist slowed down and picked up the phone while approaching the cycle path, then started to look at the phone while crossing the cycle path, and finally started texting while standing still at the red traffic light. For the MiRA requirements not categorized as necessary but useful for own safety, about half were attended to and half were not, both in the baseline and in the texting condition.

The cyclists used visual time-sharing strategies (Zwahlen et al. 1988), i.e. looking back and forth between the phone and the forward roadway, when interacting with their phones. This results in an approximately equal number of glances to the forward area as to the phone, Fig. 4. On average, the cyclists looked at other gaze targets once while texting and twice in the baseline condition, $t(21) = -3{,}43$, $p < .05$. The glance duration towards the forward area was 1.5 ± 1.5 s, towards the phone 2.1 ± 1.8 s, towards other targets 1.4 ± 1.2 s and towards other targets in baseline 1.3 ± 1.0 s. The glances towards the phone have longer duration than glances to the forward area and glances to other gaze targets ($F(3, 345) = 5.9$, $p < .05$).

For each glance towards the phone, the complexity level (see Table 1) at the start of the glance was registered, and analyses of the number of glances as well as the glance duration were carried out for each complexity level. Since there were only two glances to the phone at complexity level 3, these were removed from the analysis. The data were normalized for frequency of complexity level to compensate for imbalanced complexity level distributions. Descriptive statistics of glance durations are provided in Table 6 and Fig. 5. There were no differences in the duration of glances towards the phone between the different complexity levels ($F(2, 125) = .1$, $p > .05$).

Table 6 Descriptive statistics of the number of glances and the glance durations when looking at the phone while the cyclists wrote text messages

	Normalized number of glances	Mean duration ± std dev (s)	Median duration (s)	90th percentile duration (s)
0	208	1.9 ± 1.4	1.5	4.0
1	140	2.1 ± 1.9	1.7	4.1
2	136	2.1 ± 1.6	1.6	3.9

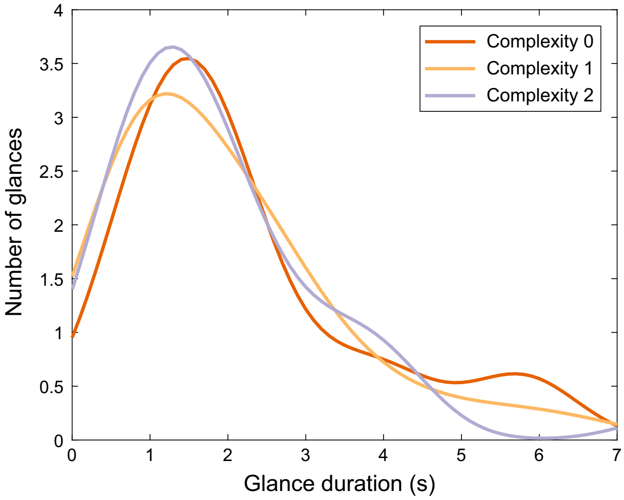

Fig. 5 Duration of glances towards the phone for the different complexity levels

4 Discussion

Listening to music via earphones did not have significant effects on workload (NASA-RTLX) or the behaviour measures examined here. This is in agreement with other studies on cyclists (Ahlstrom et al. 2016; Stelling-Konczak et al. 2018) as well as on pedestrians (Hyman et al. 2010; 2014). On the top of the list of self-reported behaviour adaptations, as a means to compensate for the loss of auditory information, is increased visual attention (Adell et al. 2014; Stelling-Konczak et al. 2017). Stelling-Konczak et al. (2018) found that 21% of the cyclists increased and 57% decreased their visual scanning to the right in intersections, when listening to music. Out of the total amount of intersections, 49% were attended in baseline and 41% in the music condition. One explanation to this behaviour might be that the cyclists are scanning the traffic scene enough using peripheral vision and do not need additional visual input. This reasoning is in line with the MiRA approach.

About half of the participants chose to handle, i.e. read or respond to, at least one text message while cycling, and one quarter never handled any text message while on a segment. This suggests that cyclists have a personal strategy with respect to the maximum complexity of interaction they accept, which may be modified by the actual circumstances. Such strategies could be to only answer the text message if the traffic light is red, but to go on cycling if the traffic light is green, or to only read text messages when there is no other traffic around and then decide whether to stop and answer or not. Such behaviours and strategies are comparable to what is typically found amongst car drivers (Funkhouser and Sayer 2012; Huth and Brusque 2013; Metz et al. 2011; Platten et al. 2014; Tivesten and Dozza 2015). Due to the design used in this study, in addition to the fact that it is not clear whether all untreated messages were ignored, or simply not noticed, it cannot be established whether the interaction level used for each message was indeed the highest acceptable for each cyclist. To pursue this further, and to establish how conscious such strategies are, more systematic studies, considering both message content, expectations about messages, and the current traffic situation would be needed.

In studies where participants know that they are being observed, they may alter their behaviour due to this awareness. This is known as the "observer effect" or "Hawthorne effect" (e.g. McCambridge et al. 2014). In this study, an effort was made to minimize the observer effect by emphasizing, both in the written instructions and later orally when informing the participants about the study on site, that we were interested in the participants' normal behaviour. This was emphasized by a few examples; it is ok to walk with your bike if you want to, interact with your phone as you normally do—it is ok to ignore or postpone incoming text messages, the follower is not there to monitor you—he is there to record what is happening around you, etc. After completing the study, the participants were asked if their behaviour was in accordance with their regular cycling and texting behaviour or if it was affected by the experimental conditions. Most riders thought it was in accordance with or fairly in accordance with their behaviour, while a minor share (four of 41 participants) thought it was not, mainly because they cycled slower than normal due to being part of the study. One of them explained this lowered speed by the effort to think aloud.

A clear majority of the necessary MiRA requirements were fulfilled for the text messages handled while cycling, while the useful MiRA requirements were sometimes attended to and sometimes not, independent of texting. Since the necessary MiRA requirements were generally fulfilled, it appears that the cyclists adopted quite successful strategies to deal with the congruent cycling and texting tasks. The participants chose whether to read the SMS, or not to read the SMS, by strategic choice and on a tactical level while taking the circumstances of the current situation into account. The cyclists seem to choose a traffic environment suitable for reading the message and if they chose to reply while cycling, they waited until the situation allowed it.

There were two occasions that resulted in three MiRA requirement breaches in the SMS condition. In the first case, the cyclist picks up his phone about 80 m from the intersection but keeps it in his hand without looking at it until after the intersection. The first actual glance to the phone occurs after having passed the intersection. In the second case, where two MiRA requirements were breached, the cyclist picks up the phone before the intersection but postpones the first glance to the phone until after the last MiRA zones have been passed. Eventually, he replies to the text message while standing still at the red light. This means that in both cases, the cyclists have started interacting with their phones when the MiRA requirements are breached, but in neither case is the cyclist looking at the phone. The first occasion, where the cyclist neglected the red light for cyclists but clearly looked at the green light for motorized traffic on the parallel road, was probably due to a misjudgement of the situation. In retrospect the participant stated that "I made a bad choice when I just went ahead. I noticed that the vehicles were standing still and therefore I decided to cross. I missed that it was still green for cars. There was a lot of traffic". There are a few ambiguities with this statement. The cyclist claims that he did not notice that the cars had a green light even though he clearly looked at the green light according to the eye tracking data. Implicitly, he states that he was aware of the red light for cyclists but decided to cross the intersection anyway since the motorized vehicles were standing still. This must have been picked up by peripheral vision since the eye tracking data show no glances to the cycle lane's red traffic light. Hence, it was non-compliance when the cyclist decided to cross the intersection despite the red light, but the unnecessary negotiation with the car was due to a misjudgement of the traffic situation. The second occasion, where the cyclist was not observed to look left and right before entering an intersecting cycle path, is harder to interpret. It is possible that the cyclist used peripheral vision or hearing to know that there was no traffic on the intersecting path. On the other hand, it is also possible that the cyclist did not focus much on the intersecting cycle path at all and hence expected it to be sufficient to come to a stop in front of the traffic light. These possibilities are not exhaustive but indicate that to understand why the necessary requirement was breached, other methods would need to be used. For instance, the participant was not required to think aloud on this segment but that could have been informative.

While interacting with their phones, the cyclists looked at other gaze targets approximately once while texting and twice in baseline, with the same glance duration per glance. Hence, glances to the phone are not only taken from the forward glances, but also from other glance targets. This is in agreement with our previous study (Ahlstrom et al. 2016) and is hence applicable to a more complex urban traffic environment than the previous study. When texting, the glances to the phone are longer than forward glances, but the complexity level did not affect glance duration to the phone. The small number of glances to the phone in situations with complexity level 3 could imply that cyclists choose not to look at the phone at high complexity levels. However, the complexity level might be too blunt a measurement, given that there were no differences in the duration of the glances towards the phone for the other complexity levels, where it was assumed possible to shut one's eyes for from less than a second to more than 3 s.

There are a few limitations to this study. Only static MiRA requirements were assessed. To also account for the prevailing traffic situation, the static MiRA requirements were complemented with a continuous encoding of the complexity level. Ideally, the complexity level should have been defined in a way that peripheral vision was considered (i.e. not based on the possibility to shut one's eyes). This is important given the capabilities of peripheral vision and the perception that can be achieved in the absence of selective attention (Wolfe et al. 2017). A road user who is looking at the phone is indeed attempting to develop situational awareness based on peripheral input alone (Wolfe et al. 2017). Future research is needed to clarify when, where and for how long peripheral input is sufficient for safe travel. In car driving, lane keeping and maintaining headway have been found to be guided mostly by peripheral vision (Bhise and Rockwell 1971; Summala et al. 1996). Also, more experienced car drivers use peripheral vision to a larger degree than novice drivers (Summala et al. 1996). It is very probable that the same is true for cycling. Also, no inter-rater reliability tests were carried out. This applies to the complexity coding, the MiRA coding and the glance coding. However, the raters were part of developing the coding scheme, and they also coded the first participants together to harmonize the ratings.

In conclusion, cyclist behaviour was not affected by music, neither in terms of subjective workload, attention, speed nor SMS interaction. No adaptation in terms of increased visual scanning could be found, but there were also no signs of decreased information intake when listening to music. For text messaging, seven different adaptation behaviours were found, from ignoring the text message, stopping the bike while reading, postponing the interaction with the phone, to instantly replying to the message. One-third of the text messages were dealt with while cycling. The overall impression was that the cyclists managed to integrate their mobile phone usage into their cycling behaviour. However, the three MiRA requirement breaches motivate further studies with larger study populations to investigate if this is a large problem and why it occurs. To understand why MiRA requirement breaches occur, a feasible way to go forward could be to make in-depth interviews with the cyclists breaching the requirements or having them think aloud from video recordings of their own behaviour.

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References

Adell E, Nilsson A, Kircher K (2014) Cyclists' use of mobile IT in Sweden—usage and self-reported behavioural compensation. In: International cycling safety conference 2014, Gothenburg, Sweden

Ahlstrom C, Kircher K, Thorslund B, Adell E (2016) Bicyclists' visual strategies when conducting self-paced vs. system-paced smartphone tasks in traffic. Transp Res Part F Traffic Psychol Behav 41:204–216

Bhise V, Rockwell TH (1971) Role of peripheral vision and time-sharing in driving Proceedings. Am Assoc Automot Med Annu Conf 15:320–341

Caird JK, Willness CR, Steel P, Scialfa C (2008) A meta-analysis of the effects of cell phones on driver performance. Accid Anal Prev 40:1282–1293. https://doi.org/10.1016/j.aap.2008.01.009

Caird JK, Johnston KA, Willness CR, Asbridge M, Steel P (2014) A meta-analysis of the effects of texting on driving. Accid Anal Prev 71:311–318. https://doi.org/10.1016/j.aap.2014.06.005

Collet C, Guillot A, Petit C (2010) Phoning while driving I: a review of epidemiological, psychological, behavioural and physiological studies. Ergonomics 53:589–601. https://doi.org/10.1080/00140131003672023

Cooper JM, Vladisavljevic I, Medeiros-Ward N, Martin PT, Strayer DL (2009) An investigation of driver distraction near the tipping point of traffic flow stability. Hum Factors 51:261–268

de Waard D, Schepers P, Ormel W, Brookhuis K (2010) Mobile phone use while cycling: incidence and effects on behaviour and safety. Ergonomics 53:30–42. https://doi.org/10.1080/00140130903381180

de Waard D, Edlinger K, Brookhuis K (2011) Effects of listening to music, and of using a handheld and handsfree telephone on cycling behaviour. Transp Res Part F 14:626–637. https://doi.org/10.1016/j.trf.2011.07.001

de Waard D, Lewis-Evans B, Jelijs B, Tucha O, Brookhuis K (2014) The effects of operating a touch screen smartphone and other common activities performed while bicycling on cycling behaviour. Transp Res Part F Traffic Psychol Behav 22:196–206. https://doi.org/10.1016/j.trf.2013.12.003

de Waard D, Westerhuis F, Lewis-Evans B (2015) More screen operation than calling: the results of observing cyclists' behaviour while using mobile phones. Accid Anal Prev 76:42–48. https://doi.org/10.1016/j.aap.2015.01.004

Ericsson KA, Fox MC (2011) Thinking aloud is not a form of introspection but a qualitatively different methodology: reply to Schooler (2011). Psychol Bull 137(2):351–354

Ericsson KA, Simon HA (1980) Verbal reports as data. Psychol Rev 87:215–251

Eriksson A, Lindström A, Seward A, Seward A, Kircher K (2014) Can user-paced, menu-free spoken language interfaces improve dual task handling while driving? In: International conference on human-computer interaction. Springer, pp 394–405

Fitch G, Grove K, Hanowski R, Perez M (2014) Compensatory behavior of drivers when conversing on a cell phone: investigation with naturalistic driving data. Transp Res Rec J Transp Res Board 2434:1–8

Funkhouser D, Sayer J (2012) Naturalistic census of cell phone use. Transp Res Rec J Transp Res Board 2321:1–6. https://doi.org/10.3141/2321-01

Goldenbeld C, Houtenbos M, Ehlers E, de Waard D (2012) The use and risk of portable electronic devices while cycling among different age groups. J Saf Res 43:1–8. https://doi.org/10.1016/j.jsr.2011.08.007

Government Offices of Sweden (2015) Lag (1951:649) om straff för vissa trafikbrott

Hart SG, Staveland LE (1988) Development of NASA-TLX (Task Load Index): results of empirical and theoretical research. In: Hancock P, Meshkati N (eds) Human mental workload. North Holland, Amsterdam, pp 139–183

Hertzum M, Hansen KD, Andersen HH (2009) Scrutinising usability evaluation: does thinking aloud affect behaviour and mental workload? Behav Inf Technol 28:165–181

Horrey WJ, Wickens CD (2006) Examining the impact of cell phone conversations on driving using meta-analytic techniques. Hum Factors 48:196–205. https://doi.org/10.1518/001872006776412135

Huth V, Brusque C (2013) Drivers´ adaptation to mobile phone use: interaction strategies, consequences on driving behaviour and potential impact on road safety. Inst Eng Technol. https://doi.org/10.1049/PBSP009E_ch9

Huth V, Sanchez Y, Brusque C (2015) Drivers' phone use at red traffic lights: a roadside observation study comparing calls and visual–manual interactions. Accid Anal Prev 74:42–48

Hyman IE, Boss SM, Wise BM, McKenzie KE, Caggiano JM (2010) Did you see the unicycling clown? Inattentional blindness while walking and talking on a cell phone. Appl Cognit Psychol 24:597–607. https://doi.org/10.1002/acp.1638

Hyman IE, Sarb BA, Wise-Swanson BM (2014) Failure to see money on a tree: inattentional blindness for objects that guided behavior. Front Psychol 5:356

Kidd DG, Tison J, Chaudhary NK, McCartt AT, Casanova-Powell TD (2016) The influence of roadway situation, other contextual factors, and driver characteristics on the prevalence of driver secondary behaviors. Transp Res Part F Traffic Psychol Behav 41:1–9

Kircher K, Ahlstrom C (2017) Minimum required attention: a human-centered approach to driver inattention. Hum Factors 59:471–484. https://doi.org/10.1177/0018720816672756

Kircher K, Patten C, Ahlström C (2011) Mobile telephones and other communication devices and their impact on traffic safety. A review of the literature. Swedish National Road and Transport Research Institute, Linköping

Kircher K, Ahlstrom C, Palmqvist L, Adell E (2015) Bicyclists' speed adaptation strategies when conducting self-paced vs. system-paced smartphone tasks in traffic. Transp Res Part F Traffic Psychol Behav 28:55–64

Kircher K, Eriksson O, Forsman Å, Vadeby A, Ahlstrom C (2017a) Design and analysis of semi-controlled studies. Transp Res Part F Traffic Psychol Behav 46:404–412. https://doi.org/10.1016/j.trf.2016.06.016

Kircher K, Nygårdhs S, Ihlström J, Ahlström C (2017b) Cyklisters interaktion med extrautrustning, infrastrukturen och andra trafikanter. En semi-kontrollerad fältstudie. Swedish National Road and Transport Research Institute, Linköping

Kircher K, Ihlström J, Nygårdhs S, Ahlstrom C (2018) Cyclist efficiency and its dependence on infrastructure and usual speed. Transp Res Part F Traffic Psychol Behav 54:148–158. https://doi.org/10.1016/j.trf.2018.02.002

McCambridge J, Witton J, Elbourne DR (2014) Systematic review of the Hawthorne effect: new concepts are needed to study research participation effects. J Clin Epidemiol 67:267–277

Metz B, Schömig N, Krüger H-P (2011) Attention during visual secondary tasks in driving: Adaptation to the demands of the driving task. Transp Res Part F Traffic Psychol Behav 14:369–380

Metz B, Landau A, Just M (2014) Frequency of secondary tasks in driving–Results from naturalistic driving data. Saf Sci 68:195–203

Metz B, Landau A, Hargutt V (2015) Frequency and impact of hands-free telephoning while driving–results from naturalistic driving data. Transp Res Part F Traffic Psychol Behav 29:1–13

Michon JA (1985) A critical view of driver behavior models: What do we know, what should we do? In: Evans L, Schwing RC (eds) Human behavior and traffic safety. Plenum Press, New York, pp 485–520

Nabatilan LB, Aghazadeh F, Nimbarte AD, Harvey CC, Chowdhury SK (2012) Effect of driving experience on visual behavior and driving performance under different driving conditions Cognition. Technol Work 14:355–363

Platten F, Schwalm M, Hülsmann J, Krems J (2014) Analysis of compensative behavior in demanding driving situations. Transp Res Part F 26:38–48. https://doi.org/10.1016/j.trf.2014.06.006

Puchades VM, Pietrantoni L, Fraboni F, De Angelis M, Prati G (2017) Unsafe cycling behaviours and near crashes among Italian cyclists. International Journal of Injury Control and Safety Promotion. https://doi.org/10.1080/17457300.2017.1341931

Schömig N, Metz B, Krüger H-P (2011) Anticipatory and control processes in the interaction with secondary tasks while driving. Transp Res Part F Traffic Psychol Behav 14:525–538

Stelling-Konczak A, van Wee GP, Commandeur JJF, Hagenzieker M (2017) Mobile phone conversations, listening to music and quiet (electric) cars: are traffic sounds important for safe cycling? Accid Anal Prev 106:10–22. https://doi.org/10.1016/j.aap.2017.05.014

Stelling-Konczak A, Vlakveld WP, van Gent P, Commandeur JJF, van Wee B, Hagenzieker M (2018) A study in real traffic examining glance behaviour of teenage cyclists when listening to music: results and ethical considerations. Trans Res Part F: Traffic Psychol Behav 55:47–57

Summala H, Nieminen T, Punto M (1996) Maintaining lane position with peripheral vision during in-vehicle tasks Human Factors. J Human Factors Ergonom Soc 38:442–451. https://doi.org/10.1518/001872096778701944

Svenson O, Patten CJ (2005) Mobile phones and driving: a review of contemporary research cognition. Technol Work 7:182–197

The Swedish Police (2017) Att använda mobilen i trafiken. The Swedish Police. https://polisen.se/Lagar-och-regler/Trafik-och-fordon/Mobilanvandning-i-trafiken/. Accessed 1 Dec 2017

The Swedish Transport Agency (2017) Mobilanvändning och annan kommunikationsutrustning. The Swedish Transport Agency. https://www.transportstyrelsen.se/sv/vagtrafik/Trafikregler/I-fordonet/Regler-for-mobilanvandning-och-kommunikationsutrustning/. Accessed 1 Dec 2017

Tivesten E, Dozza M (2015) Driving context influences drivers' decision to engage in visual-manual phone tasks: evidence from a naturalistic driving study. J Saf Res 53:87–96. https://doi.org/10.1016/j.jsr.2015.03.010

Truong LT, Nguyen HTT, De Gruyter C (2016) Mobile phone use among motorcyclists and electric bike riders: a case study of Hanoi, Vietnam. Accid Anal Prev 91:208–215. https://doi.org/10.1016/j.aap.2016.03.007

Wolfe ES, Arabian SS, Breeze JL, Salzler MJ (2016) Distracted biking: an observational study. J Trauma Nurs 23:65–70. https://doi.org/10.1097/JTN.0000000000000188

Wolfe B, Dobres J, Rosenholtz R, Reimer B (2017) More than the Useful Field: considering peripheral vision in driving. Appl Ergonom 65:316–325. https://doi.org/10.1016/j.apergo.2017.07.009

Zwahlen HT, Adams CC, DeBals DP (1988) Safety aspects of CRT touch panel controls in automobiles. In: Vision in Vehicles II. Second international conference on vision in vehicles, Nottingham, U.K.