Effects of Cycling with Headphones on Lateral Position

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Abstract

This study investigated the influence of auditory stimulus, specifically listening to music and engaging in hands-free phone calls while cycling, on the lateral position and standard deviation of the lateral position (SDLP) of cyclists. A total of 23 participants completed four experimental conditions: control, listening to music while cycling, having a handsfree-phone call while cycling, and listening to a podcast while cycling. The results of pairwise comparisons revealed no significant differences in SDLP between the control condition and either the music or phone call conditions. Similarly, no significant differences were found in the lateral position between the control condition and either the music or phone call conditions. However, participants reported a higher cognitive workload and increased distraction during the phone call condition. We conclude that auditory stimulus in the form of music or a phone call conversation does not negatively impact a cyclist swerving behavior and lateral position. Practical implications are discussed.

Keywords: Lateral position, Standard deviation of the lateral position

Effects of Cycling with Headphones on Lateral Position

Cycling is a form of physical activity that effectively taxes the cardiorespiratory and metabolic functions of the whole body in a wide range of intensities and thus lends itself to many potential health benefits (Oja et al., 2011). The study demonstrates that cycling to work or school can decrease the likelihood of experiencing heart problems, type-2 diabetes, high blood pressure, and obesity, while also enhancing physical fitness. In addition, these positive effects on health can result in financial advantages as well (Fishman et al., 2015). It may lead to lower healthcare costs, decreased absenteeism from work, increased productivity, and reduced environmental impact because of decreased utilization of automobiles. Therefore, encouraging the cycling habit could be a simple but effective way to improve both individual and societal health and well-being. Unfortunately, cyclists face a greater risk of getting hurt in a road accident (Wegman et al., 2012). Due to the human body's vulnerability and the absence of protection in the event of an accident, cyclists are considered to be at risk on the road. Collisions with motorized vehicles are a main concern for cyclists, but single-sided accidents are also a notable safety issue (Schepers, 2008). Using mobile phones while cycling has been identified as a significant factor contributing to solo bicycle accidents. According to observational studies, a majority of cyclists who made phone calls or sent text messages while cycling had only one hand on the handlebars, which will lead to reduced control (de Waard et al., 2010, Jiang et al., 2021). People will have difficulty manoeuvring, especially in situations that require quick reactions or sudden changes in direction. Cycling while only having one hand on the handlebars plus operating a mobile phone deteriorates lateral control, even when just cycling on a straight cycle path (de Waard et al., 2014). The prohibition of operating a mobile phone while cycling since 2019 has been implemented in the Netherlands, because of potential accidents due to the source of distraction. In contrast, listening to music and handsfree phone calling, which can also have an influence on cycling behaviour, have not been prohibited in the Netherlands. Countries such as Germany and New Zealand have prohibited listening to music on the bicycle (de Waard et al., 2011). According to Furnham & Strbac (2002) both mobile phone use and listening to music and handsfree phone calling will lead to worse task performance according to the distraction hypothesis. They argue that music will draw attention from work-related tasks and results in diminished performance in those tasks. This suggests that listening to music or engaging in any form of auditory stimulus (such as participating in a phone conversation) during cycling may have a detrimental effect on cycling performance. Phone conversations can be particularly detrimental in comparison with listening to music. It requires more active engagement, processing and responding to information from the conversation partner. This research aims to delve into the complex relationship between auditory stimulus and cycling performance, investigating how diverse types of sound (listening to music and a phone call) influence cycling behaviour, with the goal of potentially enhancing cycling safety and perhaps promoting the practice of cycling.

Lateral position

The term lateral position refers to the position on the road in relation to the centreline or edge of the lane, in this case the cycling lane. It describes the relative distance from the centre to the side of the lane. There are three main lateral positions that a cyclist can adopt. It is important to understand that these positions exist on a continuum, allowing for a range of options between them. Cyclists can select positions that fall between these three main positions. The first main lateral position is the centre position. This refers to riding near or on the centreline of the road. It is often used in situations where the road is narrow or there are obstacles on the side, making it safer to ride closer to the centre. When cycling in the centre position, the lateral position is at zero. Secondly, there is the right position. This refers to riding closer to the right side or the edge of the road. It is the default position for many cyclists, especially when the road is wide and there is sufficient space for both vehicles and cyclists. Riding on the right allows vehicles to pass more easily, and it is the position typically used when there is a designated bike lane. The lateral position will be greater than zero. The third will be the left position. This refers to riding closer to the left side of the road. Cyclists may choose this position in specific situations, such as when preparing for a left turn, when avoiding hazards or obstacles on the right side, or when the road is too narrow for vehicle to safely pass within the same lane. The lateral position will be smaller than zero. The lateral position of a cyclist may vary depending on the specific circumstances.

Next to the lateral position, standard deviation of the lateral position (SDLP) is also often studied when looking at cycling behaviour. SDLP indicates the variability or dispersion of the cyclist's position on the roadway, in other words swerving behaviour. A smaller SDLP means that the cyclist tends to maintain a more consistent lateral position, while a larger standard deviation indicates more variability in their position. For example, if a cyclist consistently rides in a narrow range close to the right edge of the road, their SDLP would be relatively small, indicating a more consistent position. On the other hand, if a cyclist's position varies widely between the centre, left and right side of the road, their SDLP would be larger, indicating a more variable position. This can be concerning for the safety of the cyclist and other road users, as it implies a higher risk of collision or loss of control. In the context of driving a car, SDLP has also been extensively studied regarding factors such as alcohol levels in the blood (Jongen et al., 2018). Alcohol levels in the blood is a standard measure for SDLP for driving. As blood alcohol levels rise, drivers exhibit more pronounced swerving.

Listening to music or having a phone call

Engaging in activities like phone calls and listening to music while cycling require various levels of mental workload which can impact the performance of cycling (Li et al., 2010). When listening to music or having a phone call, the ability to perceive sound is adversely impacted, resulting in a reduction in the amount of auditory input processed, like the ringing noise made by a bicycle's bell or hearing a motor vehicle approaching (Konczak et al., 2017; Jiang et al., 2021; de Waard et al., 2011). Due to the reduction in the ability to perceive sound, you may not hear motor vehicles approaching, which can be valuable information for ensuring your safety on the road. This reduction is due to a phenomenon known as ''auditory masking''. Our brain concentrates on processing the music when we listen to music, disregarding other sounds. If the intensity of the masking sound (e.g., music or phone call) is high, then the intensity of the masked sound (e.g., traffic sounds) must also be high in order to hear it (White & White, 2014). Auditory stimulus could also result in distraction by redirecting focus from the task of navigating traffic to internal experiences such as thoughts, memories, emotions, or moods (Herbert, 2013). These internal experiences can momentarily take precedence over the external demands of cycling, reducing our ability to focus on the road which could increase the risk of accidents.

Current research

The available research emphasizes the potential risks associated with distractions while cycling, particularly those related to mobile phone use. Studies have demonstrated that auditory stimulus like listening to music while cycling and engaging in a phone conversation have numerous effects that can influence the lateral positioning of a cyclist (Furnham & Strbac, 2002; Herbert, 2013; Jiang et al., 2021; Konczak et al., 2017; Li et al., 2010; de Waard et al., 2011). Interestingly, while mobile phone use has been extensively studied in relation to cycling safety, there is a scarcity of research examining the impact of listening to music or having hands-free phone conversations on a cyclist's lateral position. Understanding the potential implications is crucial for ensuring comprehensive safety guidelines that effectively address all potential distractions. In this study, we try to answer the following research question: To what extent does listening to music or phone calling impact a cyclist's lateral position?

Using the information, our first hypothesis is that earphone use while cycling increases the variability of a cyclist's lateral position (SDLP). Engaging in activities like listening to music or having a phone call while cycling introduces additional cognitive workload (Li et al., 2010). This increased mental demand may result in decreased attention to maintaining a consistent lateral position. Also based on the distraction hypothesis, the engagement with listening to music or having a phone call may divert attention away from maintaining a consistent and stable lateral position, leading to a greater SDLP (Furnham & Strbac, 2002).

Our second hypothesis is that earphone use while cycling leads to a biased lateral position towards the right side of the road. Listening to music or engaging in a phone call has a negative effect on the ability to perceive sound, like the noise of a motor vehicle approaching (Konczak et al., 2017; Jiang et al., 2021; de Waard et al., 2011). By not perceiving these cues effectively, cyclists may instinctively compensate by favouring the right side of the road in order to maintain a sense of safety by creating more distance from the traffic flow.

Method

Participants

The participants of the research were recruited by word of mouth. Convenience sampling was used. Participation in this study was entirely voluntary and participants were not compensated. The study was successfully completed by 23 people. No participants were excluded from the study. This brings the number of valid participants to $N = 23$. The mean age of the participants was 24 years old ($M = 23.61$) with a standard deviation of 6 years ($SD = 6.394$). Of these participants, 10 were female and 13 were male.

Design and Procedure

The study used a within-subjects design. The research design consisted of four experimental conditions to which the participants were randomly assigned and balanced. The conditions were randomly assigned and balanced to the participants to ensure that any observed effects on cycling performance were not due to carryover effects. Every participant completed each of the four conditions once. The following conditions were included in the experiment: (1) control condition (cycling without any type of auditory stimulus through earphones), (2) listening to music while cycling, (3) having a handsfree phone call while cycling, and (4) listening to a podcast while cycling. During each of the non-control conditions, participants were instructed to use their earphones or headphones in the manner consistent with their customary usage to create a more ecologically valid and representative experimental condition.

At least a day before their participation, the participants received an email with general information such as location and time, an information form, a map and video of the route, and a reminder to bring a charged mobile phone and earphones with a working microphone. After the participants arrived, they were again informed about the procedure, and filled out an informed consent. The participants were told to cycle as they normally would do. The participants then filled out a questionnaire, after which they completed the four conditions of the experiment in a random and balanced order. After each condition, they filled out a smaller questionnaire. After the experiment ended, a debriefing took place about the goals of the experiment, and the participants had an opportunity to ask questions. The experiment had a duration of approximately 45 to 60 minutes. The data were acquired in dry conditions during the end of May 2023.

Location

The experiment was carried out on a one-and-a-half kilometre long asphalted cycle path, in the north of Zernike Campus (see Figure 1). Most of the route was non-segregated, so cars and cyclists could be intertwined with each other. The cyclists followed the street on one side, turned left to cycle on a segregated path, crossed the street, and went left again to follow the non-segregated street until the end of the route. The cycling path itself was 1.5 kilometres long and the cycling path was 2.00 meters wide, including the white lines. The cycling path was separated with distinct colour surface and dashed white lines (see Figure 2).

Figure 1

Cycling route

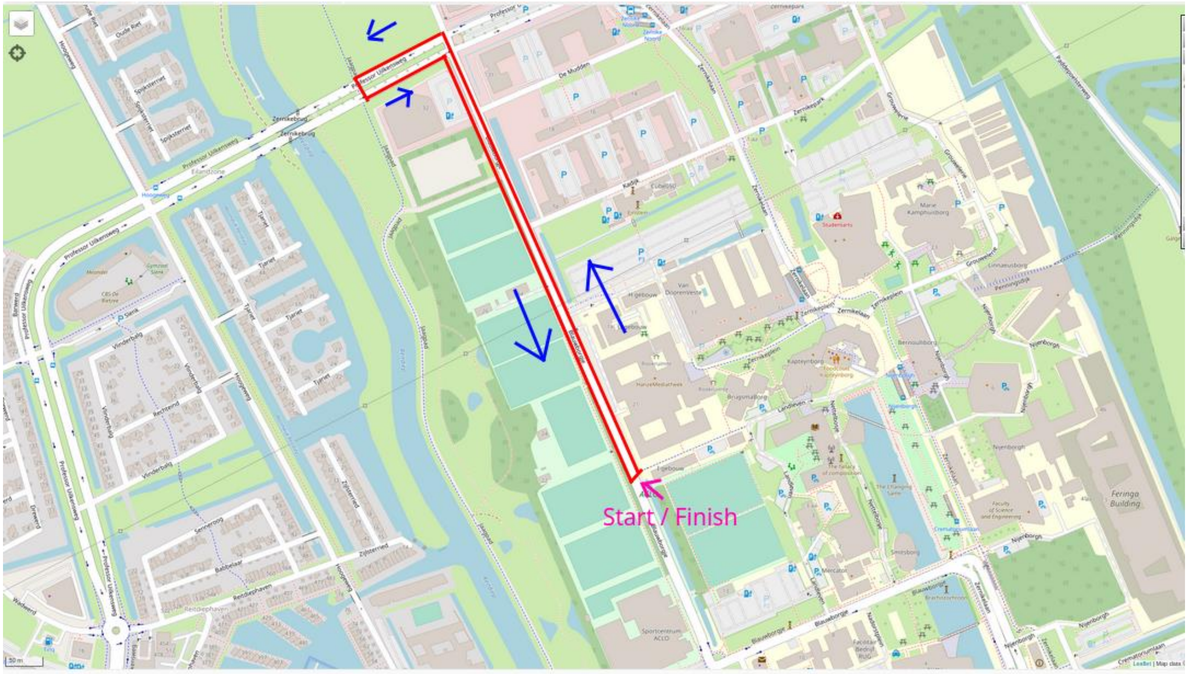


Figure 2

The cycling path.

Note. The zero point of the lateral position is located at the middle of the cycling lane.

Materials

The study utilized various materials: an online questionnaire through the Qualtrics platform (a system in which questionnaires can be created and managed), an informed consent form, an information form, two GoPro cameras with handlebar mounts, and a calibration stick. Participants were instructed to use their own bicycle, mobile phone, and earphones or headphones as part of the experimental procedure.

Questionnaire. For the current research, data was gathered using an online questionnaire in the Qualtrics platform. The data collection process involved the implementation of two distinct questionnaires. The first questionnaire (see Appendix A) was administered before the experiment began, while the second questionnaire (see Appendix B) was administered during the intervals between the experimental conditions. Notably, the in-between questionnaire exhibited distinct variations corresponding to each specific experimental condition, featuring specific sections that were relevant to each experimental condition.

The first questionnaire consisted of a total of 21 questions that encompassed various aspects including demographic information, bicycle use, cycling behaviour, the use of electronic devices while cycling, immersion experiences, and two manipulation checks. The section of bicycle use and cycling behaviour included a combination of open-ended and Likert scale questions. An example item was: ‘’I feel confident in my cycling abilities, such as handling my bike in different conditions or situations’’, which was measured using a 5-point Likert scale (1 = ‘’strongly disagree’’ to 5 = ‘’strongly agree’’).

Regarding the use of electronic devices while cycling, participants encountered multiple-choice questions and Likert scale questions. Example items were: ‘’What kind of earphones/headphones do you use while cycling? (Multiple answers are possible)’’ (answer options: ‘’noise cancelling headphones or earphones’’, ‘’non-noise cancelling headphones’’, ‘’non-noise cancelling earphones’’, ‘’other’’) and ‘’What do you usually do when you are cycling on an (electric) bike or moped/scooter and you receive a phone call?’’.

Immersion-related questions were answered using a 6-point Likert scale. An example item was: ‘’I often become completely engrossed in a movie or TV show’’ (1 = ‘’strongly disagree’’, 2 = ‘’disagree’’, 3 = ‘’not agree, not disagree’’, 4 = ‘’agree’’, 5 = ‘’strongly agree’’, 6 = ‘’don’t know / no opinion’’).

To evaluate if the questionnaire was answered honestly by the participants, manipulation checks were incorporated within the questionnaire. One particular question, namely ‘’Answer ‘disagree’ on this question’’ served as a means to assess whether participants were responding honestly or randomly. This measure aimed to verify the participants’ engagement with the questionnaire. If a participant answered any other answer than ‘disagree’ their questionnaire would be excluded from the analysis due to the inability to ensure the accuracy and sincerity of their answers.

The in-between questionnaire consisted of four standard questions related to immersion, distraction, and working memory. These questions were: ‘’I was absorbed in my thoughts’’, ‘’I was aware of what was happening around me’’, ‘’My attention was on cycling alone (so no daydreaming and or being distracted by my surroundings)’’, and ‘’I used a lot of my working memory during the ride’’. All these questions were answered with a rating scale from 1 to 10, where 1 meant ‘’not at all’’ and 10 meant ‘’completely’’. The podcast and music conditions incorporated additional questions. In the music condition, participants were presented with an extra item regarding the genre of music they were listening to, utilizing a multiple-choice format that included various music genres as options. The podcast condition included several supplementary open-ended questions that focused on the content of the podcast.

Measures

Lateral position. The term lateral position refers to the position on the road in relation to the centreline or edge of the lane, in this case the cycling lane The standard deviation of the lateral position (SDLP) indicates the variability or dispersion of the cyclist’s position on the roadway, in other words swerving behaviour. The measurement of the cyclists’ lateral position and SDLP involved the placement of a GoPro camera in a strategic position that allowed for capturing the front wheel of the bicycle. To establish an accurate calibration, a 1.5 metre calibration stick was employed, serving two purposes: determining the lateral distance from the wheel to any pixel on the left side of the cyclist, and correcting for lens distortion. The alignment of the wheel and stick formed a 90-degree angle with the road edges. The measurement of lateral position was based on the distance to the white stripes situated on the left side of the cyclist. See Figure 3 for the setup.

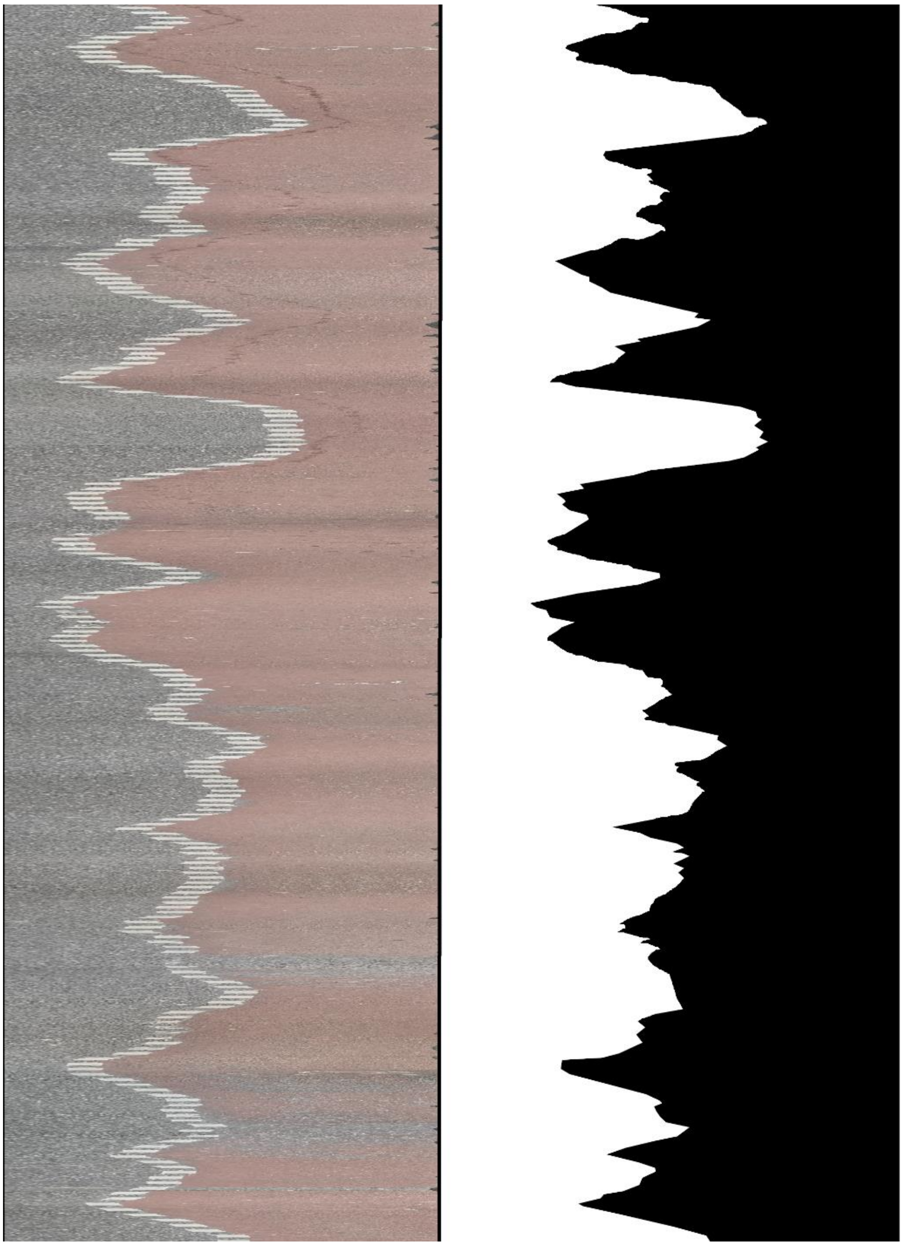
Prior to commencing cycling, a brief video was recorded for the purpose of extracting a calibration image. By capturing a screenshot from the video, a calibration image was obtained which was used to manually mark the length of the calibration stick (see Figure 4). While making the picture it was important to ensure that the image of the road edge was clear and easily distinguishable. At the end of each measurement process, the procedure of generating a calibration image was repeated. The software application GIMP, which specializes in photo editing, was used to enhance clarity of the final image (see Figure 4). Additionally, a line was drawn on the image to indicate the lateral position of the wheel. Subsequently, the GIMP image, the desired start and end time for measurement, and the corresponding video file made by the GoPro camera were imported into MATLAB, a programming environment, for further analysis and processing.

Figure 3

Calibration setup

Figure 4

Calibration image (left) and calibration image after photo editing with GIMP (right)



Exploratory variables. In addition to assessing lateral position, this study used questionnaires to measure various additional variables (see Appendix B). These variables included distraction and cognitive workload, which were measured with the in-between questionnaire on 1 a scale of 1 to 10, with 1 indicating ‘’not at all’’ and 10 indicating ‘’completely’’. Using a rating scale allowed for the quantification of subjective experiences, enabling to analyse and compare the data more effectively. Cognitive workload was measured using the question: ''I used a lot of my working memory during the ride''. Distraction was measured using the question ''I was aware of what was happening around me''. By incorporating these measures, the study aimed to gather a comprehensive understanding of various aspects related to participants' cycling behaviours during the experimental conditions. This allowed for a more thorough analysis of the data and insights into how these factors may impact participants' cycling behaviour. Furthermore, head movements and speed were also measured, however, it should be noted that they were not analysed in this particular study.

Results

The analysis of the SDLP focused specifically on the three conditions: control, listening to music and phone call. Table 1 shows the means and standard deviations for SDLP for the control condition (*M* = 22.13, *SD* = 4.50), the music condition (*M* = 20.74, *SD* = 5.98), and the phone call condition (*M* = 20.13, *SD* = 5.72). Figure 5 illustrates the variation in SDLP between the three conditions.

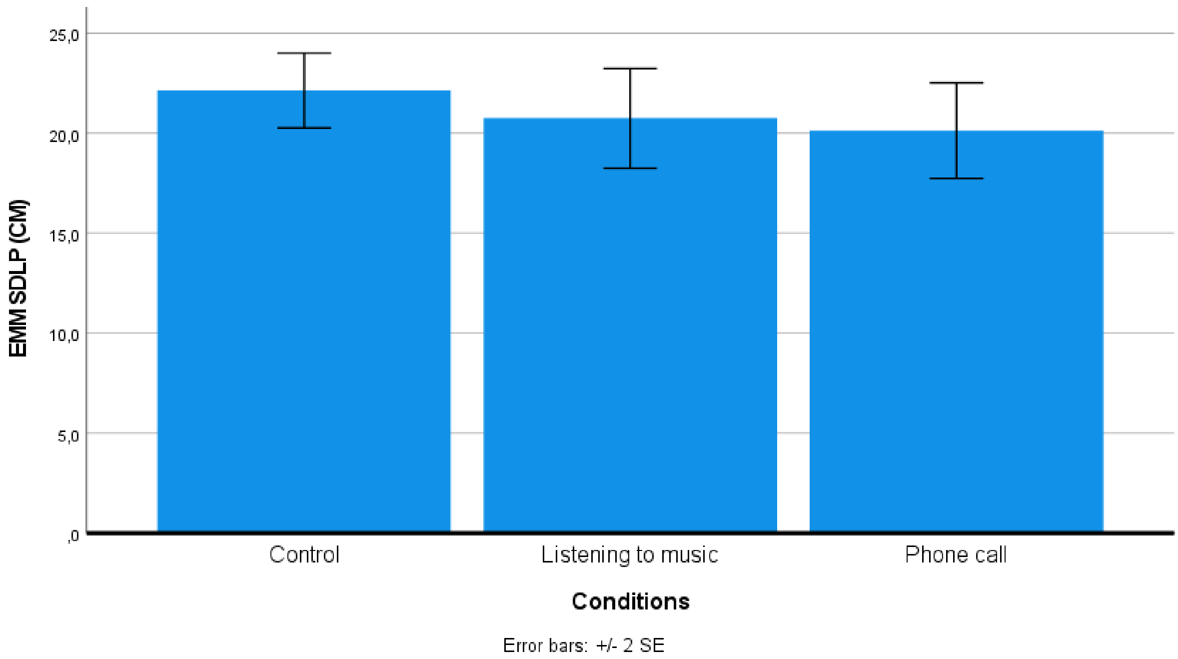
Table 1

Means, Standard Deviations and Participants of the SDLP

	M	*SD*	*N*
SDLP control condition	*22.13041830*	*4.497208520*	*23*
SDLP music condition	*20.74291926*	*5.977641041*	*23*
SDLP phone call condition	*20.12766774*	*5.720635066*	*23*

Figure 5

Estimated Marginal Means of SDLP for Each Condition



To compare the SDLP of the three conditions a repeated measures general linear model (GLM) approach was conducted implemented in the statistical software package SPSS. The utilization of a repeated measures design allowed for the examination of within-subjects effects and the exploration of how variables may change over time or in different conditions.

Based on the Mauchly's Test of Sphericity, it can be concluded that the data used in the pairwise comparisons of the SDLP (see Table 4) satisfies the assumption of sphericity (*p* = 0.414). The p-value indicates that there is no significant violation of the assumption. Therefore, the results obtained from the pairwise comparisons of the SDLP can be interpreted with the assumption that the variances of the differences between condition pairs are equal. The F statistic and partial eta squared given in Table 3 support these findings, F (2, 21) = 1.403, p = 0.268, η_p^2 = 0.118. The p-value is 0.268, which is above the significance level of 0.05. Following the ANOVA, post hoc pairwise comparisons were conducted to further examine specific differences between the conditions. It should be noted that the observed differences in SDLP between the conditions, as indicated by the pairwise comparisons in Table 4, are relatively small. The pairwise comparisons of the SDLP provided in Table 4 suggests a slight variation between condition 1 (control condition) and condition 2 (listening to music while cycling condition) (*M* = 1.4, *SE* = 0.991). The p-value (*p* = 0.526) indicates that this difference is not statistically significant. Table 4 also shows a slight variation between condition 1 and condition 3 (phone call condition) (*M* = 2.003, *SE* = 1.231). However, similar to the comparison with condition 2, the p-value (*p* = 0.354) indicates a lack of statistical significance. Also, the 95% confidence intervals (95% *CI* [-1.179, 3.954], 95% *CI* [-1.188, 5.193]) include a range of values which include zero, indicating the possibility of no substantial difference in SDLP between the compared conditions. Based on both the small differences and lack of statistical significance, we cannot conclude that there is a significant differences and lack of statistical significance, we cannot conclude that there is a significant difference in the SDLP between neither the listening to music while cycling condition nor the phone call condition when compared to the control condition.

Table 3

Multivariate Tests of the SDLP

	Value	*F*	*Hypothesis df*	*Error df*	*Sig.*	*Partial Eta Squared*	*Observed Power*[p]
Pillai's trace	*0.118*	*1.403*[a]	*2.000*	*21.000*	*0.268*	*0.118*	*0.267*
Wilks' lambda	*0.882*	*1.403*[a]	*2.000*	*21.000*	*0.268*	*0.118*	*0.267*
Hotelling's trace	*0.134*	*1.403*[a]	*2.000*	*21.000*	*0.268*	*0.118*	*0.267*
Roy's largest root	*0.134*	*1.403*[a]	*2.000*	*21.000*	*0.268*	*0.118*	*0.267*

Note. Each F tests the multivariate effect of Conditions. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

b. Computed using alpha = .05

Table 4

Pairwise Comparisons of the SDLP

(I) Conditions	*(J) Conditions*	*Mean difference (I-J)*	*SE*	*Sig[a]*	*95% Confidence Interval for Difference[a]*	
					Lower Bound	*Upper Bound*
1	*2*	*1.387*	*0.991*	*.526*	*-1.179*	*3.954*
	3	*2.003*	*1.231*	*.354*	*-1.188*	*5.193*
2	*1*	*-1.387*	*0.991*	*.526*	*-3.954*	*1.179*
	3	*0.615*	*1.025*	*1.000*	*-2.042*	*3.272*
3	*1*	*-2.003*	*1.231*	*.354*	*-5.193*	*1.188*
	2	*-0.615*	*1.025*	*1.000*	*-3.272*	*2.042*

Note. Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Similarly, Table 5 shows the means and standard deviations for lateral position for the control condition (*M* = 106.80, *SD* = 20.87), the music condition (*M* = 110.19, *SD* = 22.42), and the phone call condition (*M* = 103.30, *SD* = 22.73). Figure 6 illustrates the variation in the lateral position between the three conditions.

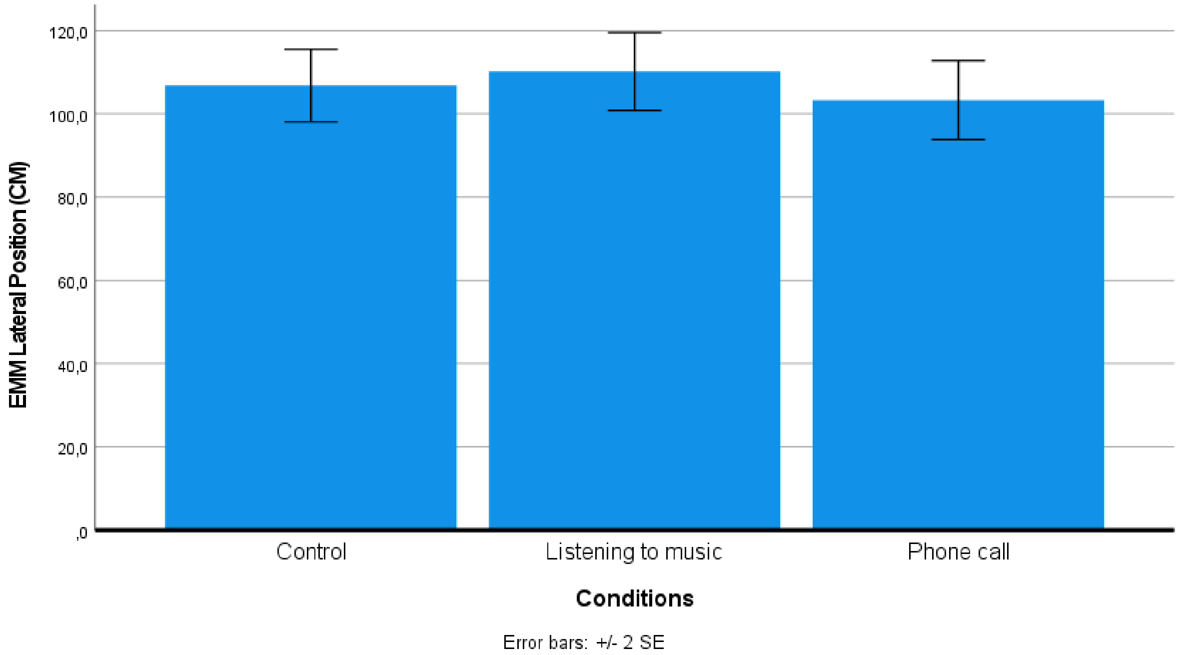
Table 5

Means, Standard Deviations and Participants of the Lateral Position

	M	*SD*	*N*
Average Lateral Position control condition	*106.79991352*	*20.871632591*	*23*
Average Lateral Position music condition	*110.18769730*	*22.422165746*	*23*
Average Lateral Position phone call condition	*103.29678957*	*22.725118178*	*23*

Figure 6

The Estimated Marginal Means of the Lateral Position for Each Condition



The same repeated measures general linear model (GLM) approach was used to analyse the data. Data shows that there is no significant violation of the assumption of sphericity based on Mauchly's Test of Sphericity (p = 0.574), indicating that the results obtained from the pairwise comparisons of the lateral position (Table 7) can be interpreted with the assumption that the variances of the differences between condition pairs are equal. The F statistic and partial eta squared given in Table 6 support these findings, F (2, 21) = 2.624, p = 0.096, η_p^2 = 0.464. The p-value is 0.268, which is above the significance level of 0.05. Following the ANOVA, post hoc pairwise comparisons were conducted to further examine specific differences between the conditions. The Pairwise comparisons of the lateral position provided in Table 7 suggests a slight variation between the three conditions. When comparing condition 1 with condition 2, the mean difference M in lateral position was -3.388 (SE = 2.705, p = 0.671, 95% CI [-10.397, 3.622]). The mean difference suggests that individuals in condition 2 tend to cycle more towards the left side, suggesting a greater deviation from the centre position compared to condition 1. The p-value of 0.671 indicates that the difference between these two conditions is not statistically significant. Similarly, when comparing condition 1 to condition 3, the mean difference *M* in lateral position was 3.503 (*SE* = 3.300, *p* = 0.900, 95% *CI* [-5.047, 12.053]). The p-value of 0.900 shows that there is no statistically significant difference also between these two conditions. Although the direction of the mean difference is positive, indicating a tendency to cycle more towards the right side, we cannot conclude that there is a significant difference in the lateral position between neither the listening to music while cycling condition nor the phone call condition when compared to the control condition.

Table 6

Multivariate Tests of the Lateral Position

	Value	*F*	*Hypothesis df*	*Error df*	*Sig.*	*Partial Eta Squared*	*Observed Power*[b]
Pillai's trace	*0.200*	*2.624*[a]	*2.000*	*21.000*	*0.096*	*0.200*	*0.464*
Wilks' lambda	*0.800*	*2.624*[a]	*2.000*	*21.000*	*0.096*	*0.200*	*0.464*
Hotelling's trace	*0.250*	*2.624*[a]	*2.000*	*21.000*	*0.096*	*0.200*	*0.464*
Roy's largest root	*0.250*	*2.624*[a]	*2.000*	*21.000*	*0.096*	*0.200*	*0.464*

Note. Each F tests the multivariate effect of Conditions. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. *Exact statistic*

b. *Computed using alpha = .05*

Table 7

Pairwise Comparisons of the Lateral Position

(I) Conditions	*(J) Conditions*	*Mean difference (I-J)*	*SE*	*Sig*[a]	*95% Confidence Interval for Difference*[a]	
					Lower Bound	*Upper Bound*
1	*2*	*-3.388*	*2.705*	*0.671*	*-10.397*	*3.622*
	3	*3.503*	*3.300*	*0.900*	*-5.047*	*12.053*
2	*1*	*3.388*	*2.705*	*0.671*	*-3.622*	*10.397*
	3	*6.891*	*3.011*	*0.096*	*-0.911*	*14.693*
3	*1*	*-3.503*	*3.300*	*0.900*	*-12.053*	*5.047*
	2	*-6.891*	*3.011*	*0.096*	*-14.693*	*0.911*

Note. Based on estimated marginal means

a. *Adjustment for multiple comparisons: Bonferroni.*

Exploratory variables

In Table 8 the means, standard deviations, and variances of the measured cognitive workload are presented for each of the three conditions. Cognitive workload was measured using the question: ‘’I used a lot of my working memory during the ride’’. Participants who rated higher on this question, reported a higher cognitive workload. Table 9 shows the pairwise comparisons for cognitive workload between the three conditions. The comparison between the music condition and control condition indicates a non-significant mean difference of M = -0.391 (SE = 0.434, p = 1.000). However, the comparison between condition 3 and condition 1 reveals a significant difference of M = 2.957 (SE = 0.493, p = <.001), indicating that participants in condition 3 experienced a significantly higher cognitive workload compared to condition 1.

Table 8

Cognitive Workload (Question 4)

	Control condition	Music condition	Phone call condition
M	4.17	3.78	7.13
N	23	23	23
SD	2.059	2.110	1.140
Variance	4.241	4.451	1.300

Note. The cognitive workload measure was rated on a scale from 1 to 10, with 1 representing ‘’not at all’’ and 10 representing ‘’completely.’’

Table 9

Pairwise Comparisons Cognitive Workload

(I) Conditions	(J) Conditions	Mean difference (I-J)	SE	Sig[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
Control	Music	0.391	0.434	1.000	-0.734	1.517
	Phone call	-2.957*	0.493	<.001	-4.234	-1.679
Music	Control	-0.391	0.434	1.000	-1.517	0.734
	Phone call	-3.348*	0.469	<.001	-4.563	-2.133
Phone call	Control	2.957*	0.493	<.001	1.679	4.234
	Music	3.348*	0.469	<.001	2.133	4.563

Note. Based on estimated marginal means

**. The mean difference is significant at the .05 level.*

a. Adjustment for multiple comparisons: Bonferroni.

Table 10 presents the means, standard deviations, and variances of the measured distraction for each condition. Distraction was measured using the question ‘’I was aware of what was happening around me’’. Participants who rated lower on this question, reported being more distracted. Table 11 provides the pairwise comparisons for distraction between the conditions. The comparison between condition 2 and condition 1 reveals a significant mean difference of *M* = -0.609 (*SE* = 0.215, *p* = 0.030), suggesting that participants in condition 2 reported a higher level of distraction compared to condition 1. Similarly, the comparison between condition 3 and condition 1 indicates a significant mean difference of *M* = -2.130 (*SE* = 0.472, *p* <.001), indicating that participants in condition 3 reported an even higher level of distraction compared to condition 1.

Table 10

Distraction (Question 2)

	Control condition	*Music condition*	*Phone call condition*
M	*8.61*	*8.00*	*6.48*
N	*23*	*23*	*23*
SD	*0.988*	*1.314*	*2.274*
Variance	*0.976*	*1.727*	*5.170*

Note. The distraction measure was rated on a scale from 1 to 10, with 1 representing ‘’not at all’’ and 10 representing ‘’completely.’’

Table 11

Pairwise Comparisons Distraction

(I) Conditions	*(J) Conditions*	*Mean difference (I-J)*	*SE*	*Sig*[b]	*95% Confidence Interval for Difference*[b]	
					Lower Bound	*Upper Bound*
Control	*Music*	*0.609**	*0.215*	*0.030*	*0.51*	*1.167*
	Phone call	*2.130**	*0.472*	*<.001*	*0.908*	*3.353*
Music	*Control*	*-0.609**	*0.215*	*0.030*	*-1.167*	*-0.051*
	Phone call	*1.522**	*0.360*	*0.001*	*0.588*	*2.456*
Phone call	*Control*	*-2.130**	*0.472*	*<.001*	*-3.353*	*-0.908*
	Music	*-1.522**	*0.360*	*0.001*	*-2.456*	*-0.588*

Note. Based on estimated marginal means

**. The mean difference is significant at the .05 level.*

a. *Adjustment for multiple comparisons: Bonferroni.*

Discussion

This study investigated the relationship between auditory stimuli (listening to music and engaging in hands-free phone calls) and cycling performance, with a focus on the lateral position and the standard deviation of the lateral position (SDLP), swerving, of cyclists on the cycling road. The research hypothesis stated that auditory stimuli in the form of music or phone conversations while cycling increases the variability of a cyclist's lateral position, measured as SDLP. Engaging in activities like listening to music or having a phone call introduces additional cognitive workload, which may decrease attention to maintaining a consistent lateral position (Li et al., 2010). The results of the F statistic were not statistically significant (p = 0.268). Therefore, there is not enough support to reject the null hypothesis that there is no significant difference between the estimated marginal means of the conditions being compared. Also, the pairwise comparisons show that the differences between the conditions are not statistically significant. This suggests that listening to music or engaging in phone calls while cycling, does not significantly affect the SDLP of a cyclist. This demonstrates that activities like listening to music or having a phone call while cycling do not seem to have a significant negative impact on a cyclist's SDLP. This implies that cyclists may engage in these activities without substantial risk of compromising their ability to maintain safe cycling behaviour in terms of SDLP.

It was also hypothesized that auditory stimulus in the form of music and phone conversation while cycling may lead to a biased lateral position towards the right side of the road due to reduced awareness of auditory cues (Konczak et al., 2017; Jiang et al., 2021; de Waard et al., 2011). The statistical analysis of the F statistic and pairwise comparisons conducted on the lateral position between the three conditions did not yield any statistically significant differences. This shows that engaging in activities like listening to music or having a phone conversation while cycling does not lead to changes in the lateral position. Therefore, it implies that these activities did not a have a negative impact on maintaining safe cycling behaviour in terms of lateral position.

The study’s findings show that there were significant differences in distraction levels and cognitive workload between the conditions. Participants in the listening to music condition reported a higher level of distraction compared to the control condition. Participants during the phone call condition reported an even higher level of distraction. Moreover, the pairwise comparisons for cognitive workload indicated that participants during the phone call condition experienced also a significant higher cognitive workload compared to the control condition.

Although the results of the SDLP and lateral position showed a slight variation between the conditions, these differences were not found to be statistically significant. Therefore, while the conditions have an impact on cognitive workload and distraction, they do not directly result in significant changes in lateral position or SDLP. However, it is important to note that while these activities may not directly lead to swerving or biased lateral positioning, distraction can still be a potential issue. It is possible that the increase in distraction could have other effects that were not specifically measured in the study, like head movements. Additional research is needed to fully understand the nature and extent of these relationships.

There are several possible explanations for finding non-significant differences in the present study. One possible explanation for the non-significant differences in lateral position and SDLP observed in the study is that participants have developed compensation mechanisms, like adjusting speed, enhancing focus and attention, or employing strategies to prioritize the cycling task while minimizing distractions. Participants might have consciously or subconsciously adjusted their cycling behaviour to compensate for the potential distractions or cognitive workload associated with listening to music or having phone calls. For example, they might have adopted a more cautious approach or focused more on maintaining their position on the road, counteracting any potential negative effects. Furthermore, participants might have already been accustomed to cycling while listening to music or having a phone conversation while cycling. This might have further facilitated their ability to adapt and compensate effectively. Their compensation mechanisms and task familiarity could have contributed to maintaining their cycling performance without significant changes in lateral position or SDLP.

Another possible explanation is that the sample size in the study was insufficient to detect meaningful differences between the conditions. A larger sample size boosts the study´s statistical power, enabling it to detect even small variations that may be statistically significant. However, considering the small differences in lateral position and SDLP, it may be questioned whether the expectation of finding significant results with a larger group is warranted.

Limitations

A noteworthy limitation is that the research was conducted at a specific location and time. The research took place on a 1.5 kilometre cycle path situated in the north of Zernike Campus during May 2023. As a result, the findings may be influenced by the specific characteristics of the chosen location and the seasonal factors. Factors such as road conditions, traffic density, and weather circumstances can play a significant role in cycling behaviour and safety. Road conditions, including the presence of obstacles, surfacy quality, or the layout of the cycling path, can affect a cyclist’s position and stability. Traffic density, such as the volume and behaviour of vehicles, can also impact a cyclist’s ability to maintain a steady position. Additionally, weather circumstances, such as wind speed or precipitation, can introduce additional challenges and alter cycling dynamics. Therefore, it is crucial to recognize that the results obtained from this study may not be generalizable to other cycling contexts and time periods.

It is also important to consider that the phone call condition in the present study might not be fully representative of real-world phone conversations while cycling. The study utilized a structured phone call scenario where participants were engaged in storytelling and had to answer specific questions. This controlled and directed interaction differs from the spontaneous and varied nature of typical phone conversations during cycling in everyday life. The use of a scripted phone call scenario can have implications for the cognitive workload experienced by participants. In a structured phone call scenario where participants are engaged in storytelling and asked specific questions, the cognitive demands may be different compared to a more naturalistic phone conversation. Caution is warranted when generalizing these findings to real-world scenarios involving phone calls.

Future research

In conclusion, the present study did not find significant differences in SDLP or lateral position between the control condition, the music condition, and the phone call condition. However, it revealed that engaging in a phone call while cycling increases cognitive workload and both conditions lead to higher levels of distraction compared to the control condition. These findings contribute to our understanding of the effects of earphone use and cognitive factors on cycling behaviour. Future research should explore these effects in larger and more diverse samples. In light of the limitations and findings of the current research, there are several directions for future research that can help deepen our understanding of the effects of auditory stimuli on lateral position and SDLP. Firstly, using a naturalistic phone conversation. By simulating real-world phone conversations while cycling, researchers can investigate the impact of more authentic interactions on variables such as lateral position, SDLP, and cognitive workload. Another direction for future research is investigating the influence of various contextual factors, such as road conditions, traffic density, and weather circumstances, on the relationship between auditory stimuli and cycling performance. Understanding how these factors interact with auditory stimuli can help identify specific conditions where the impact on SDLP and lateral position may be more pronounced. At last, a potential direction for future research could be to further investigate and understand the specific compensation mechanisms employed by cyclists to mitigate the potential negative effects of auditory stimuli. Conducting a quantitative study to objectively measure and assess the effectiveness of compensation mechanisms employed by cyclists. This could involve using advanced technologies such as motion sensors, eye-tracking devices, or physiological measurements to capture and analyse the adjustments made by cyclists in response to auditory stimuli, like music and phone calls. By quantifying these compensation strategies, researchers can gain insight into their effectiveness and determine which specific behaviours or adjustments contribute to maintaining cycling performance.

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Appendix A

Participant number:

____

Cycling with headphones

Q1 How old are you?

____

Q2 How much sleep did you get last night?

- ○ less than 4 hours (1)
- ○ more than 4, less than 6 (2)
- ○ more than 6, less than 8 (3)
- ○ more than 8 (4)

s

Q3 What kind of earphones/headphones do you use while cycling? (multiple answers are possible)

- ☐ noise cancelling headphones or earphones (1)
- ☐ non noise canceling headphones (2)
- ☐ non noise canceling earphones (3)
- ☐ other (4)

Q4 How many times per week do you cycle?

____

Q5 How many cycling accidents have you had in the last 2 years?

____

Answer This Question If:

The answer to the previous question is greater than 0

Q6 In how many of these accidents were you using earphones or headphones?

____

Q7 I feel confident in my cycling abilities, such as handling my bike in different conditions or situations

- strongly disagree (1)
- disagree (2)
- neutral (3)
- agree (4)
- strongly agree (5)

Q8 I feel that I have good balance and coordination while cycling

- strongly disagree (1)
- disagree (2)
- neutral (3)
- agree (4)
- strongly agree (5)

Q9 When you listen to music while cycling, do you change the way you ride your bike in any way? If you do, what do you do differently? (multiple answers are possible)

- ○ Cycling with one earbud (1)
- ○ Turning the volume down (2)
- ○ Cycling slower (3)
- ○ Cycling faster (4)
- ○ Making less head movements (5)
- ○ I don't listen to music while cycling (6)
- ○ I do not change the way I cycle (7)

Q10 When you make a phone call while cycling, do you change the way you ride your bike in any way? If you do, what do you do differently? (multiple answers are possible)

- ○ Cycling with one earbud (1)
- ○ Turning the volume down (2)
- ○ Cycling slower (3)
- ○ Cycling faster (4)
- ○ Making less head movements (5)
- ○ I don't make phone calls while cycling (6)
- ○ I do not change the way I cycle (7)

Q11 I feel that listening to music while cycling makes me less aware of my surroundings

- ○ strongly disagree (1)
- ○ disagree (2)
- ○ neutral (3)
- ○ agree (4)
- ○ strongly agree (5)

Q12 I feel that calling while cycling makes me less aware of my surroundings

- strongly disagree (1)
- disagree (2)
- neutral (3)
- agree (4)
- strongly agree (5)

Q13 I feel that listening to music while cycling is distracting and negatively impacts my performance

- strongly disagree (1)
- disagree (2)
- neutral (3)
- agree (4)
- strongly agree (5)

Q14 What do you usually do when you are cycling on an (electric) bike or moped/scooter and you receive a phone call?

- I answer the phone while cycling (1)
- I stop immediately and answer the phone (2)
- I wait until it's quiet and call back while cycling (3)
- I wait until it's quiet and stop to call back (4)
- I ignore the ringing (5)
- I never hear it (6)
- That never happens (7)

Q15 What do you usually do when you are cycling on an (electric) bike or moped/scooter and you hear/feel that a new message has arrived on your phone or smartwatch?

- I message back while cycling (1)
- I stop immediately and message back (2)
- I wait until it's quiet and message back while cycling (3)
- I wait until it's quiet and stop to message back (4)
- I ignore it (5)
- I never hear it (6)
- That never happens (7)

Q16 Answer 'disagree' on this question.

- strongly disagree (1)
- disagree (2)
- neutral (3)
- agree (4)
- strongly agree (5)

Q17 I think I am able to hear traffic around me when cycling with music or while listening to a podcast

- strongly disagree (1)
- disagree (2)
- neutral (3)
- agree (4)
- strongly agree (5)

Q18 To what extent do you agree or disagree with the following statement:

When I am working on something, I easily lose track of time

- Strongly disagree (1)
- Disagree (2)
- Not agree, not disagree (3)
- Agree (4)
- Strongly agree (5)
- Don't know/ no opinion (6)

Q19 I can easily block out external distractions when I am focused on something else

- Strongly disagree (1)
- Disagree (2)
- Not agree, not disagree (3)
- Agree (4)
- Strongly agree (5)
- Don't know/ no opinion (6)

Q20 I often become completely engrossed in a movie or TV show

- Strongly disagree (1)
- Disagree (2)
- Not agree, not disagree (3)
- Agree (4)
- Strongly agree (5)
- Don't know/ no opinion (6)

Q21 Have you answered this questionnaire honestly?

○ No (1)

○ Yes (2)

Appendix B

Start of Block: Between conditions questionnaire **CONDITION: 1 (Normal)**

Q1 I was absorbed in my thoughts
(choose an answer between 1 and 10; 1 = not at all, 10 = completely)

____

Q2 I was aware of what was happening around me
(choose an answer between 1 and 10; 1 = not at all, 10 = completely)

____

Q3 My attention was on cycling alone (so no daydreaming and or being distracted by my surroundings)
(choose an answer between 1 and 10; 1 = not at all, 10 = completely)

____

Q4 I used a lot of my working memory during the ride
(choose an answer between 1 and 10; 1 = not at all, 10 = completely)

____

Start of Block: Between conditions questionnaire: **CONDITION: 2 (Music)**

Q1 I was absorbed in my thoughts
(choose an answer between 1 and 10; 1 = not at all, 10 = completely)

____

Q2 I was aware of what was happening around me
(choose an answer between 1 and 10; 1 = not at all, 10 = completely)

____

Q3 My attention was on cycling alone (so no daydreaming and or being distracted by my surroundings)
(choose an answer between 1 and 10; 1 = not at all, 10 = completely)

____

Q4 I used a lot of my working memory during the ride
(choose an answer between 1 and 10; 1 = not at all, 10 = completely)

____

Q5 What kind of music did you listen to while cycling?

- ○ Hip Hop / Rap
- ○ Rock
- ○ Dance / EDM (Techno, House, Dubstep)
- ○ R & B
- ○ Classical music
- ○ Other: ________________

Start of Block: Between conditions questionnaire **CONDITION: 3 (Call)**

Q1 I was absorbed in my thoughts
(choose an answer between 1 and 10; 1 = not at all, 10 = completely)

____

Q2 I was aware of what was happening around me
(choose an answer between 1 and 10; 1 = not at all, 10 = completely)

____

Q3 My attention was on cycling alone (so no daydreaming and or being distracted by my surroundings)
(choose an answer between 1 and 10; 1 = not at all, 10 = completely)

____

Q4 I used a lot of my working memory during the ride
(choose an answer between 1 and 10; 1 = not at all, 10 = completely)

____

Start of Block: Between conditions questionnaire **CONDITION: 4 (Podcast)**

Q1 What was the first drug Steve-o talked about?

____

Q2 How many Steve-o's were in the bed?

____

Q3 How many days did his ketamine trip last?

____

Q4 What other drug did Steve-O combine with using cocaine?

____

Q5 What did Steve-o think about not being able to do when he got a bad trip from ketamine?

____

Q6What happened to Steve-o's hotel room when he was on a ketamine trip?

____

Q7 What was Steve-o’s higher power?

____

Q8 I was absorbed in my thoughts
(choose an answer between 1 and 10; 1 = not at all, 10 = completely)

____

Q9 I was aware of what was happening around me
(choose an answer between 1 and 10; 1 = not at all, 10 = completely)

____

Q10 My attention was on cycling alone (so no daydreaming and or being distracted by my surroundings)
(choose an answer between 1 and 10; 1 = not at all, 10 = completely)

____

Q11 I used a lot of my working memory during the ride
(choose an answer between 1 and 10; 1 = not at all, 10 = completely)

____