# The Effect of Solely Descriptive Auditory Route Cues on Navigation Performance of Cyclists

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***Abstract* — In this day and age society strives to improve road safety. Legal prohibitions are introduced that prevent holding an electronic device while riding a bicycle. These prohibitions are meant to reduce the number of road casualties by reducing the need for divided attention. Although handsfree usage of electronic devices is still allowed, visual route guidance displayed in front of the user might still distract the cyclist too much. Therefore, the goal of this study was to find out if the navigation performance of cyclists improves whilst attention is divided over two sensory domains in comparison to just one domain. An interactive virtual system with stationary bicycle was used to simulate a bike ride through an unfamiliar urban environment. We examined the navigation performance of cyclists whilst using solely descriptive auditory route cues, in comparison to using only visual navigation instructions and using visual guidance with descriptive auditory route cues. Results show significant differences in navigation performance between groups. Participants using solely auditory guidance had a significant higher reaction time than participants using solely visual guidance. Moreover, participants using solely visual guidance made significantly less mistakes than participants using either visual and auditory guidance or solely auditory guidance. Although results show that navigation performance is negatively influenced when attention is divided over two sensory domains, our findings provide valuable input for future research on reducing the need for divided attention in navigation tasks.**

***Index Terms* — Navigation, Wayfinding, Locomotion, Route Descriptions, Descriptive Route Cues, Landmark Navigation, Assistive Technology, Situational Awareness**

## I. Introduction

In this day and age society strives to improve road safety. In the Netherlands more and more laws and regulations have risen in the past two decades. Since 2002 it has been forbidden to hold an electronic device while driving a motor vehicle, moped or motorized vehicles for the disabled. In 2009 this regulation was also applied to electronic bicycles. These laws and regulations are meant to reduce the number of road casualties by reducing the need for divided attention.

In July 2019 a new regulation was introduced to extend the prohibition to cyclist as well. Recent research shows that 49 percent of Dutch consumers use their mobile phones while cycling. This percentage is even higher between the ages 18 and 24: 75 percent [1]. This implies a large proportion of the Dutch population needs to adjust their behavior in traffic, especially using navigation aids while cycling.

The prohibition of the use of electronic devices does not only refer to sending text messages, listening to music or crawling the web, but also affects using navigation apps, like *Google Maps*. It is important to note that handsfree use of an electronic device is still allowed. People can use voice commands, earphones to operate the device or attach their device to the dashboard or handlebar of a vehicle, as long as the device is not in one's hands.

Divided attention is of great importance in terms of road safety, since trying to carry out multiple tasks based on visual processing, i.e. navigating, may lead to interference. Looking at the handsfree options, one might wonder whether attaching an electronic device to a handlebar is the most optimal way to reduce the need for divided attention. This presents the question for other possibilities in terms of non-visual navigation aids, e.g. solely auditory or tactile assistance, and whether these other options reduce the need for divided attention whilst navigating.

Therefore, the goal of this study was to find out if the navigation performance of cyclists improves whilst attention is divided over two sensory domains in comparison to just one domain. To find the answer, we examined the navigation performance of cyclist whilst using solely descriptive auditory route cues, in comparison to using only visual navigation instructions and using visual guidance with descriptive auditory route cues.

If results show that navigation performance is improved while attention is divided over two sensory domains, it would mean that situational awareness in traffic could be improved, as less demand is placed on visual processing. However, if navigation performance is negatively influenced, more research can be done on other forms of navigational aids, e.g. tactile assistance, where the need for divided attention is reduced.

## II. Literature Background

First a definition of terms is presented. Next the following topics are covered to get a better understanding of the relevant scientific context: navigation performance, route descriptions, landmark navigation, bicycle navigation, the rise of assistive technologies, road safety and finally the effects of multisensory information processing.

### *A. Definition of Terms*

Navigation entails a complex task in which both cognitive and motoric elements are combined. Since there is some discrepancy in the definition of terms within the scientific field of navigation, the following definition is adopted for the remainder of this research:

*Navigation is the aggregate task of wayfinding and motion* [2]

Wayfinding entails a multisensory cognitive process in which humans need to use and manipulate information to find their way in all kinds of environments. This process can also be defined as the development and use of cognitive maps, in which humans make a mental representation using their spatial knowledge.

Within the scientific field of navigation several terms are used when referring to the motoric element of navigation: motion, travel and transport. Although these terms could be used interchangeably, the type of motion that best describes the motoric tasks for the remaining part of this research is: *locomotion*. Also known as *active transport.*

Generally situational awareness can be seen as the perception of environmental components, the understanding of these components, the explanation of their current state and the ability to project the same in the near future.

Finally, divided attention is generally described as the ability to process two or more sources of information. Divided attention is required when people perform multiple tasks at the same that all require attention.

### *B. Navigation Performance*

Navigation performance entails how well we are able to navigate from one point to another [3]. There are different ways to measure navigation performance in terms of effectiveness. Previous studies used various number of errors and time required as part of their measurement of navigation performance [3]–[6]. However, navigational expertise [7], gender, age [8]–[10] and individual navigation preferences [11] all influence our navigation performance. This implies that the variables that are researched within a study might result in different findings regarding navigation performance.

### *C. Route Descriptions*

There are several ways to convey route descriptions. Studies have shown that descriptive route cues result in a better navigation performance in regards to survey cues [12], [13]. Not only do route cues enhance navigation performance in both speed and effectiveness [13], [14], but the use of landmarks in these descriptions also enhances route learning and remembering [8].

### *D. Landmark Navigation*

A lot of research has been done on the use of landmarks in navigation tasks. In one study a combination of both visual and auditory route cues was used to study the effectiveness of navigation with and without the use of landmarks [8]. Although the study showed that there was a significant difference in route learning, it did not specifically show a difference in overall navigation performance. This implies that the use of landmarks only positively influences the cognitive part of navigation and has no significant influence on locomotion. Since navigation consists of both cognitive and motoric tasks, one might argue that a change in one of both influences the overall navigation performance.

Another study showed that navigation abilities overall are not influenced by gender when global landmarks are used in route descriptions [15]. However, there is a clear distinction between the way males and females navigate with incorporated landmarks. This implies that the way you measure navigation performance, might influence the total outcome.

One other important factor in using landmarks in route descriptions is landmark recognition time. Not only might this cognitive burden influence navigation performance, but it also depends heavily on the type of landmark used in navigation tasks [16]. Fortunately several studies were conducted in which a feasible model for landmark saliency was put together [17]. With the help of these models the influence of the type of landmark could be brought to a minimum, while selecting the proposed landmarks at decision points in route descriptions.

### *E. Bicycle Navigation*

Little research has been done on bicycle navigation. One possible reason is that cycling is not a primary mode of transportation in a great part of the world. Nevertheless, some interesting studies have been done that relate to bicycle navigation. Some of the important findings showed that cyclists prefer a short travel distance and reduced number of turns [10], [18]. Moreover, cyclists' route preferences depend heavily on the bike path characteristics, i.e. the quality of the bike path and whether their route offers clear distant vision [18], [19]. This implies that decisions during bicycle navigation are influenced by cyclists' perception of both immediate and distant surroundings.

### *F. Rise of Non-Visual Assistive Technologies*

In time several assistive technologies emerged or were developed to complement the highly complex process of navigation. Studies have shown that in highly complex tasks people are more likely to use assistive technologies to minimize cognitive burden [20], [21].

We are all familiar with route guidance apps like *Google Maps* and a large part of the population uses this navigation aid in day to day live. However, a large part of these aids still relies on visual guidance. This makes one wonder whether people are able to navigate with non-visual aids.

An interesting study showed that users were able to navigate by solely tactile feedback in an environment without any landmarks [22],which shows people are capable of navigation without visual guidance. This observation is confirmed by a research where visual impaired individuals were asked which and how environmental auditory cues were used for navigation[23]. Although this study showed that people are able to navigate on environment sound alone, it still leaves the question open for navigation by descriptive auditory route cues.

Another research showed that with GPS-enhanced voice guidance no distinction between descriptive auditory route cues and survey cues can be made in navigation performance [24]. Although this contradicts other research in which descriptive route cues where perceived more effective than survey cues, the study showed that pedestrians are capable to navigate with voice-only guidance.

### *G. Road Safety*

In terms of road safety situational awareness plays a big role. Not only did the concept of situational awareness receive more attention in the past two decades, but more research is being done on how to improve situational awareness. While moving through traffic cyclists need to take context information into consideration and predict possible future states of this context. This might concern temporal, spatial and environmental information [21].

One study showed that it is important that assistive technologies take infrastructure, road environment, vehicles and vulnerable road users into account while aiding humans in navigational tasks [25]. Another study showed that situational awareness rises as the cognitive burden of a tasks lowers [26]. This is an interesting factor to consider in the study of navigation by assistive technologies. If in fact solely auditory route descriptions demand a higher cognitive burden than visual guidance, situational awareness might lower and thus have a negative influence on road safety.

### H. Effects of Multisensory Information Processing

Several studies have shown the benefits of multisensory information processing on highly complex cognitive tasks. Benefits include improvement in reaction time and reliability in visual processing tasks [27]–[29]. In relation to the highly complex task of navigation studies have shown that navigation performance improves when multisensory guidance is used compared to using one sensory guidance [5], [6].

Finally an interesting study was done on the effects of multisensory presentation on spatial memory and navigation performance in virtual environments [30]. Although the researchers showed that multisensory input benefits route recall and wayfinding abilities, they used environmental auditory input in their experiments. One might wonder what the multisensory information processing effects are on navigation, when descriptive auditory route cues are used.

## III. METHOD

The goal of this study was to find out if the navigation performance of cyclists improves whilst attention is divided over two sensory domains in comparison to just one domain. Therefore, we examined the navigation performance of cyclist whilst using solely descriptive auditory route cues, in comparison to using only visual navigation instructions and using visual guidance with descriptive auditory route cues.

### A. Ethical Approval

Ethical approval was obtained from the Psychology Research Ethics Committee of Leiden University before research was conducted. Since personal data was gathered and processed, a Research Data Processing Inventory was also conducted beforehand as a part of the ethical approval application.

### B. Apparatus

Real environment experiments can be unpredictable, especially when there are several external factors involved. For this study specifically, real life traffic situations might have a great influence on the experiment. Therefore, we have opted for a controlled interactive virtual environment, in which a participant needs to use physical movement to travel through a virtual urban environment.

In this study we have used an existing technology, Bike Labyrinth, www.bikelabyrinth.com. The technology offers interactive virtual bike tours, that are made from video recordings of people cycling through cities or nature. This technology is originally intended for people with mental or physical disabilities. Users can explore a city by cycling on a stationary bicycle that is connected to a monitor. The software contains decision points in which a user can choose between two directions to continue their bike ride. Customizations and additions have been made in order to suit our experiment, which will be explained in the following sections.

#### 1) Hardware of the Interactive Virtual Installation

Figure 1 shows a diagram for the hardware used in this study. The regular installation consists of a special manufactured computer (6), containing the Bike Labyrinth software, that is connected to a TV (1) via an HDMI cable. Furthermore, a stationary bicycle with two buttons on the handlebar and a pedal sensor and their corresponding transmitters (3 and 4) and receivers (7) are also part of the regular installation.

One of the additions made for this study, is the attachment of a smartphone (2) on the handlebar of the bicycle, which is connected to a play/pause button (9). Furthermore, a keyboard for the experimenter (8) is attached to the Bike Labyrinth computer (6). Lastly, headphones for the participants (5) that are connected to a separate laptop (10) are used in this study’s installation as well.

*2) The Working of the Interactive Virtual Installation*

The TV showed the participants the virtual urban environment they cycled through from a first-person perspective. The magnetic pedal sensor on the bicycle tracked whether a participant was cycling. This output is sent via a keystroke transmitter to the corresponding receiver. As long as the participants kept cycling, the virtual bike ride would continue. The speed of the cyclist did not influence the duration of the virtual bike ride, since the videos in the virtual tour were set at a constant framerate. However, if a participant stopped cycling, the virtual bike ride would have paused and a notification on the monitor would appear, stating “You have stopped”.

As soon as participants came across a decision point, a blue and a yellow arrow appeared on the screen alongside a notification to choose a direction. Participants could either press the blue (left or straight ahead) or yellow (right or straight ahead) button. The signal of these button presses was sent via a keystroke transmitter to the corresponding receiver. The computer registered their decision and the next video would be loaded.

Depending on whether the decision that the participant made, was correct or not, the next video would either contain the next part of the virtual bike ride or an error screen. In case the error screen appeared, the experimenter would use the keyboard to manually reload the previous video and bring the participant back, with key combination V, I and P, to the decision point where the participant made the mistake.

The smartphone was used to display a video recording of a simulated navigation route. At the start of the bike ride, the experimenter would press the play button in order to start the video. Whenever a participant made an error the video was paused, simulating that the visual navigation has stopped as well. As soon as the participant continued their bike ride, the play button was pressed so that video continued. The smartphone did not display a play or pause icon, whenever the button was pressed, nor did the brightness of the screen change. Therefore, we could assume participants could not notice that the smartphone was manually controlled.

The headphones connected to the laptop were used for the auditory instructions. The same video that was displayed on the smartphone, was used to convey auditory route cues. Whenever a participant made an error the video on the laptop was paused, until the participant was once again back on track. Lastly, the video was never paused during auditory cues; therefore, we could assume participants could not notice that the auditory instructions were manually controlled.

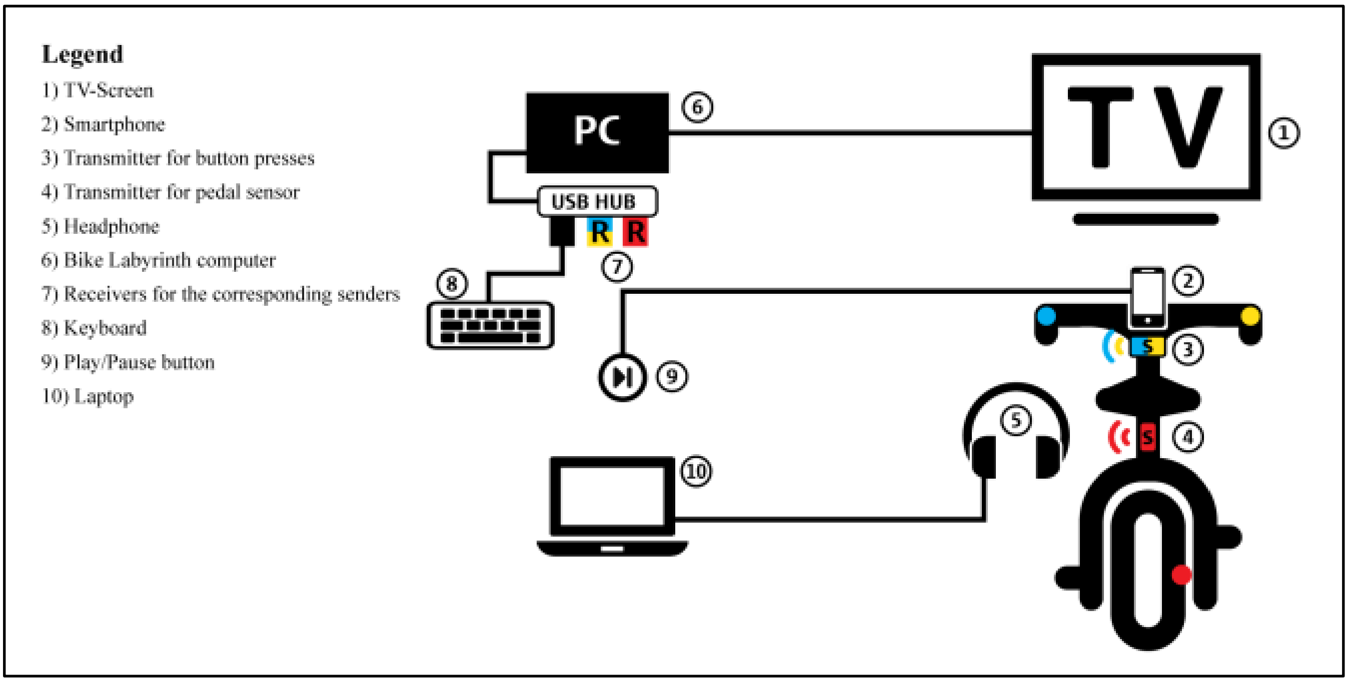


Fig. 1. Diagram of the hardware used in this study.

Pilot tests showed instability of wireless connections between the smartphone and the play/pause button and between the headphones and the laptop. Therefore, we have chosen to use only wired connections to bring the risk of technical issues to a minimum.

### *C. Experiment Design*

#### *1) Route design*

Route design was based on unfamiliarity of the environment, quality of the videos, route length and the number of decision points. Several pilot tests were performed, with the existing routes of Bike Labyrinth. Based on these tests we found that none of the already available routes contained enough decision points for our experiment.

Therefore, we considered two options: either we could film a new route with enough decision points and have total control over the route, or we could construct a new route from available content. Since the latter option was more time convenient, we opted to build or own route from already available video recordings of bike rides through Philadelphia (USA).

The reconstruction of an existing route, entailed cutting the videos in pieces to create more decision points. Although we were limited to the available content, we were able to create a route of approximately 10 minutes and 9 seconds, with 22 decision points, which would result in enough data points to perform statistical analyses. Figure 2 shows the final route that was used in the experiments.

#### *2) Navigation instructions*

Visual navigation instructions were made using the OsmAnd navigation app. With this app we were able to load a GPX file of our route, extracted from Google Maps, and simulate the navigation route. By recording the screen whilst the app was simulating a bike ride through Philadelphia, we were able to create a video that served as visual navigation instruction in our experiment. As shown in fig. 3 the blue arrow resembled the location of the participant in the virtual bike ride, whereas the blue line resembled the route the participants had to follow.

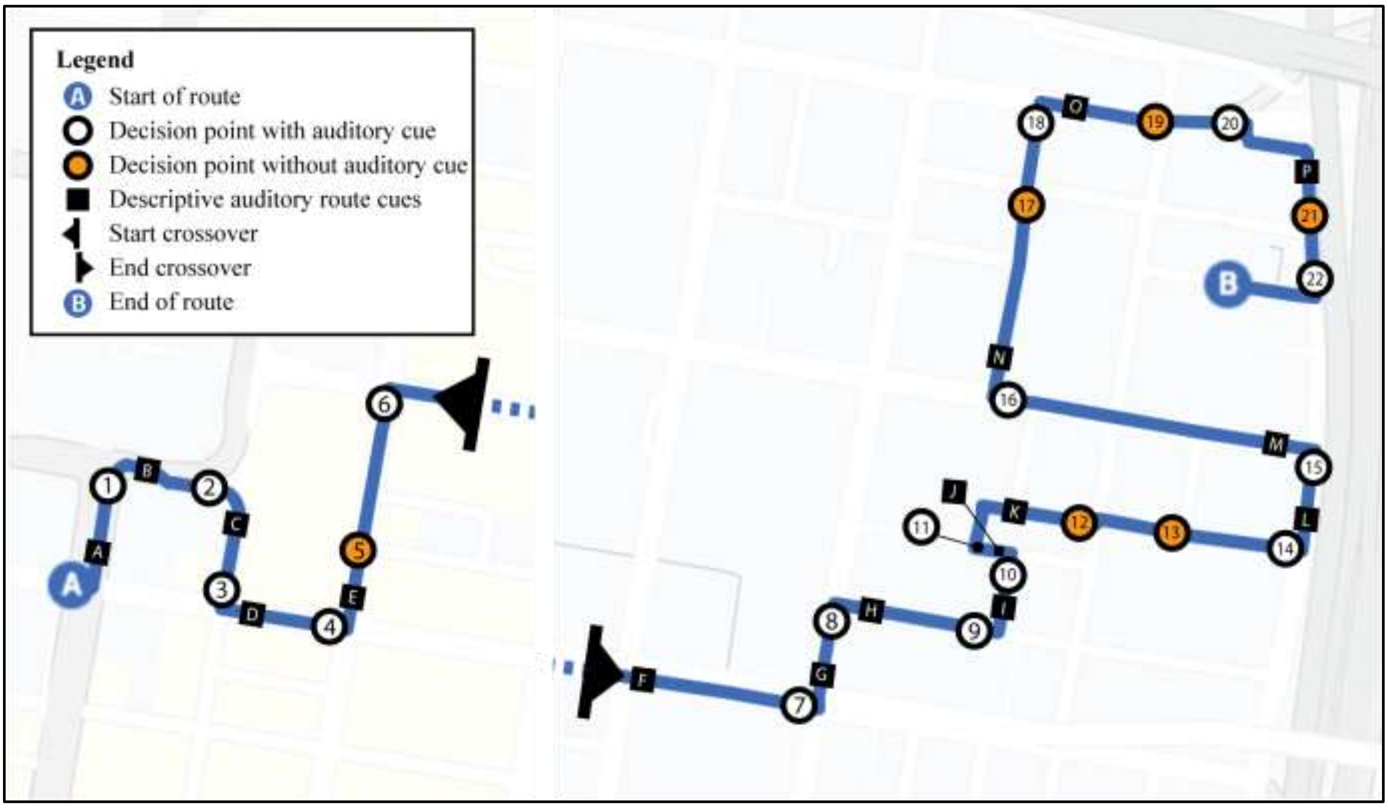


Fig. 2. Map of the route through the city of Philadelphia (USA).


Fig. 3. A screenshot of the video that served as the visual navigation instructions in our experiment.

Descriptive audio route cue instructions were created following the guidelines for good descriptive route cues as presented in previous studies [4], [14]. Furthermore, we have looked at existing navigation apps, i.e. Google Maps and Wayz, in order to determine when and in which sequence an auditory cue is presented. Although these navigation apps do not use descriptive route cues, they follow the same rules regarding timing and sequence.

Elaborative auditory cues are not only given at the start of a route, but also after each action taken, e.g. if you just turned right, a new auditory cue is given well before the following needed action: "Turn left after 100 meters". Moreover, just before an action is needed a short auditory cue is given as reminder, e.g. "Turn left".

Regarding the sequence in which an elaborative auditory cue is given, both apps start with the direction of the action, followed by the place where the action needs to take place, i.e. "Turn left at the next crossing".

As shown in Fig. 2 we incorporated descriptive auditory cues well before a change of direction was needed. Furthermore, all decision points where participants needed to change direction, contained a short reminder of the needed action. These reminders were presented just a moment before the arrows of the decision point appeared on the screen and thus the participant needed to make a decision. An overview of the given auditory instructions, can be found in Appendix I.

*3) Conditional groups*

Each participant completed the same route, but different navigation instructions were presented based on the conditional group the participant was assigned to. All navigation instructions were given at the same points in the route and were not time depended. The three conditions are described below:

**Visual.** In this condition participants followed a visual aid on a smartphone, i.e. a blue line that shows the correct route and a blue arrow that resembled their own location.

**Visual-Auditory.** In this group, participants were presented both visual navigational aid and descriptive auditory cues.

**Auditory.** The participants in this group only had descriptive auditory navigational aid.

## D. Procedure

After reading an information letter and signing an informed consent form, participants were asked to fill in a preliminary questionnaire with basic questions as age, gender and dexterity. Lastly, participants were also asked to indicate on a Likert scale whether they know their way around the city of Philadelphia, if they have ever been there.

Next, a Corsi block-tapping test [31] was conducted to assess participants' spatial short-term working memory. We conducted both the forward and the backward Corsi block-tapping test and kept score using a Corsi scoring form, see Appendix II. If the participant completed the sequence correctly 1 point was recorded, whereas an incorrect completion was scored with a 0. The total Corsi score was calculated by adding the correct number of sequences of both the forward and backward test. Participants received explanation on both the workings and the purpose of the test.

After the spatial short-term memory test was conducted, participants were asked to take place on the stationary bicycle. Whilst participants made themselves comfortable, instructions on the workings of the installation and the experimental task were given. All participants were told that they were going to bicycle through the city of Philadelphia and that their task was to follow the navigational instructions as good as possible. Participants were explained that they will come across multiple intersections where a blue and yellow arrow will appear on the screen, each heading to a different direction, see fig. 4 as an example.


Fig. 4. Simulating a participant of the Visual-Auditory group during the experiment at a decision point.

Next, they were told that depending on the given navigation instructions, they needed to press the corresponding blue or yellow button on the handlebar of the bicycle to go into the correct direction. Participants were explained that when they made a mistake, they would notice it immediately by the appearance of a red cross on the monitor. They were also told that they would be brought back to the decision point where they made the error, to make the decision at the same point again. Lastly, each participant was clearly told if they would receive visual and/or auditory instructions.

Depending on the conditional group the participants were in, additional instructions were given. The Visual group was explained, that they needed to use the visual instructions given on the smartphone in front of them. They were specifically told to follow the blue line on the map and that the location indicator would move along with them. The Auditory group was explained that they would receive navigational auditory cues during their bike ride. The Visual-Auditory group received both of the above instructions. In addition, they were told that both the visual and the auditory navigation instructions were in sync and do not contradict each other. Finally, the experiment started as soon as the participant told the experimenter they were ready.

As soon as the bike ride was over, participants were asked about the quality of the received navigation instructions via a questionnaire. Lastly, a short debriefing was provided.

### *E. Measurements and Calculations*

We measured number of errors and total reaction time and as indicators of navigation performance. In order to measure the total reaction time we have video recorded the monitor for each experiment and analyzed the recordings to calculate the total reaction time. All videos were analyzed with the video editing software Adobe Premiere Pro.

#### *1) Number of Errors*

Each time a participant made a mistake at a decision point, i.e. pressed the wrong button, resulting in the appearance of the error screen, it was recorded as one error.

*2) Total Reaction Time*

For this study, the total reaction time in seconds was calculated with the following formula:

**Total Reaction Time** = Total Task Time – Total Error Time – Total Pre-Recorded Route Time

**Total Task Time.** The video recordings of each participant were analyzed. Not only does the route start with a distinct bell sound, but the end of the route is both visual and auditory distinguishable as well. In this way we could pinpoint the start and end time of the task, up until 1/100 second. By extracting the start time from the end time, we could calculate the total task time in seconds per participant.

**Total Error Time.** If participants made any mistakes, total error time needed to be calculated as well. Time per error was calculated by extracting the timecode of the first incorrect button press from the timecode of the correct button press at the corresponding decision point. Just like the start and the end of the route, button presses were both visually and auditory distinguishable in the video recordings. In this way we could pinpoint each button press, with 1/100 second accuracy.

For example: If a participant made an error at decision point 5, at 130.54 seconds, the error screen would be loaded and the participant would be brought back to decision point 5. If the participant now presses the correct button, say at 141.34 seconds, he will continue his bike ride. The time per error in this case would be: 141.34 – 130.54 = 10.80 seconds.

Two participants made the same two errors at a decision point. In these cases, the second incorrect button press was ignored, resulting in a longer error time for that specific decision point.

Finally, the total error time was calculated by adding all times per error.

**Total Pre-Recorded Route Time.** The total duration of the route is a fixed value (i.e. 609.18 seconds). This value was calculated by adding the duration of each video within the route. In further explanation: if a participant made 0 errors and had a total reaction time of 0.00 seconds, their total task time would be equal to the total pre-recorded route time.

## IV. Results

SPSS for Mac, Version 24 was used for statistical analysis. Throughout this work in all statistical tests significance is determined with $\alpha$ (0.05).

### *A. Participants*

Data from two participants were omitted from analyses due to technical issues within the experiment. Furthermore, we have identified one outlier in the number of errors within the Visual group. The data point from this participant was more than 3 standard deviations away from its group mean. Since this data point significantly differed from other observations, we omitted the data of this participant from analyses.

The remaining 47 participants (Table I) were young adults, who were self-reported in physical healthy condition, experienced cyclists and were aware of common traffic rules and regulations. Although subjects were not tested on their visual and audio acuity, all participants had normal or corrected to normal vision and hearing.

A preliminary questionnaire showed that five participants have visited the city of Philadelphia in the past. However, these participants all stated that they visited the city three or more years ago and stayed less than two weeks in the city. Moreover, they all indicated that they did not know their way around the city. Therefore, we can state that none of the

TABLE I. Participants' characteristics

| *Group*[a] | Participants (N) | Age (years) mean (SEM) | Corsi score mean (SEM) |
|---|---|---|---|
| V (F) | 7 | 26.4 (0.8) | 18.9 (0.8) |
| V (M) | 8 | 25.9 (1.1) | 18.8 (0.6) |
| **V (F+M)** | **15** | **26.1 (0.7)** | **18.8 (0.5)** |
| VA (F) | 7 | 24.7 (1.1) | 19.9 (0.6) |
| VA (M) | 9 | 27.2 (1.0) | 19.6 (0.9) |
| **VA (F+M)** | **16** | **26.1 (0.8)** | **19.7 (0.6)** |
| A (F) | 8 | 27.8 (1.0) | 18.1 (0.8) |
| A (M) | 8 | 28.5 (0.6) | 19.2 (0.5) |
| **A (F+M)** | **16** | **28.1 (0.7)** | **18.8 (0.7)** |
| Total (F) | 22 | 26.5 (0.6) | 19.0 (0.4) |
| Total (M) | 25 | 27.2 (0.6) | 19.2 (0.5) |
| **Total (F+M)** | **47** | **26.8 (0.4)** | **19.1 (0.3)** |

a. V: Visual, VA: Visual-Auditory and A: Auditory participants had *a priori knowledge* of the urban environment they cycled through.

The Corsi block-tapping test was conducted to verify that participants had an overall and within groups similar spatial short-term working memory. As shown in Table I, the means of the Corsi scores are similar between and within groups.

### B. Number of Errors

The Kolmogorov-Smirnov test showed that the number of errors in the Visual-Auditory group, $D(16) = 0.21$, $p = 0.06$, follow a normal distribution. The number of errors in the other two groups, Visual, $D(15) = 0.47$, $p < 0.001$ and Auditory, $D(16) = 0.22$, $p < 0.05$, were both significantly non-normal. Moreover, Levene's test of homogeneity of variances showed that the assumption of homogeneity was not met for the number of errors, $F(2, 44) = 3.82$, $p < 0.03$.

Since the assumptions of normality has been violated, a one-way ANOVA test could not be conducted for the total number of errors. Therefore, we have conducted the non-parametric Kruskal-Wallis test to analyze the number of errors.

The number of errors were significantly affected by the type of navigational guidance participants received, $H(2) = 13.08$, $p < 0.01$. Mann-Whitney tests, with an applied Bonferroni correction of 0.0167 level of significance, were used to follow up this finding. Although the test showed that there was no significant difference between groups Visual-Auditory and Auditory, ($U = 126.50$, $r = -0{,}01$), there were significant differences between groups Visual and Visual-Auditory, ($U = 41.50$, $r = -0{,}60$), and between groups Visual and Auditory, ($U = 48.00$, $r = -0{,}56$). This implies that participants with solely visual guidance made significantly less mistakes than participants with either visual and auditory guidance or solely auditory guidance. This can also be observed in Table II by comparing the means for the number of errors of each group.

### C. Total Reaction Time

The total reaction time for all three groups showed a normal distribution; Visual, $D(15) = 0.16$, $p > 0.2$, Visual-Auditory, $D(16) = 0.19$, $p = 0.13$ and Auditory, $D(16) = 0.19$, $p = 0.12$. However, Levene's test revealed that for the total reaction time, $F(2, 44) = 8.05$, $p < 0.01$, the variances were significantly different within each group.

Since the assumption of homogeneity of variances is not met for the total reaction time, we used the Welch test to obtain the adjusted $F$-ratio. For the total reaction time the one-way ANOVA showed a significant difference between at least two groups, Welch's $F(2.00, 26.55) = 5.07$, $p = 0.01$, *est.* $\omega^2$ 0.15.

Post hoc comparisons using Games-Howell test were carried out. There was a significant difference (Mean Difference = 7.48) between the Auditory and Visual group ($p = 0.01$, $d = 1{,}14$). This implies that participants with solely auditory guidance had a significant higher reaction time than participants with solely visual guidance. This can also be observed in Table II by comparing the means for the total reaction time in seconds.

TABLE II. DESCRIPTIVE STATISTICS

| *Group* | **Participants (N)** | **Nr. of Errors mean (SEM)** | **Nr. of Errors minimum** | **Nr. of Errors maximum** | **Total Reaction Time (seconds) mean (SEM)** | **Total Reaction Time (seconds) minimum** | **Total Reaction Time (seconds) maximum** |
|---|---|---|---|---|---|---|---|
| Visual | 15 | 0.27 (0.15) | 0.00 | 2.00 | 18.39 (0.97) | 14.02 | 25.42 |
| Visual-Auditory | 16 | 1.50 (0.33) | 0.00 | 4.00 | 20.26 (1.77) | 11.26 | 36.16 |
| Auditory | 16 | 1.50 (0.32) | 0.00 | 5.00 | 25.87 (2.12) | 13.78 | 37.49 |
| **Total** | **47** | **1.11 (0.18)** | **0.00** | **5.00** | **21.57 (1.08)** | **11.26** | **37.49** |

### D. Gender

Three separate Mann-Whitney U tests showed that there was no significant difference in number of errors between genders in the Visual group ($U$ = 17.50, $p$ = 0.08), the Visual-Auditory group ($U$ = 31.00, $p$ = 0.96) and the Auditory group ($U$ = 21.00, $p$ = 0.23). These outcomes are visually presented in Fig. 5.

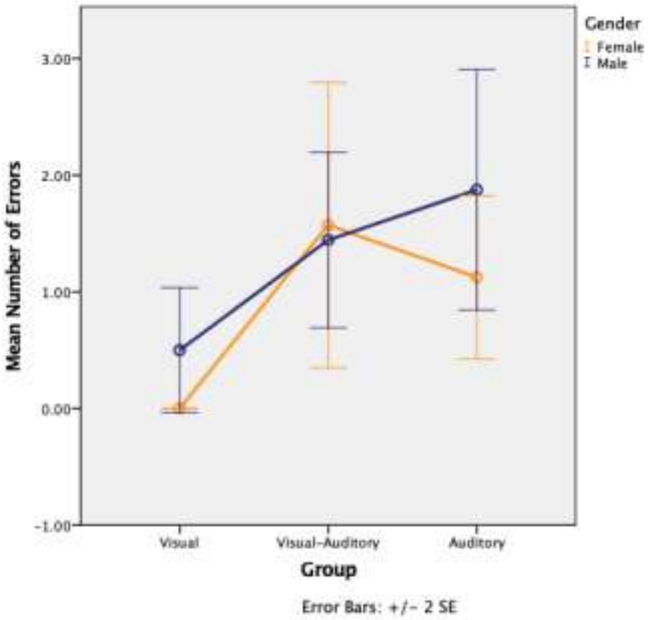


Fig. 5. Means plot of number of errors per gender per group

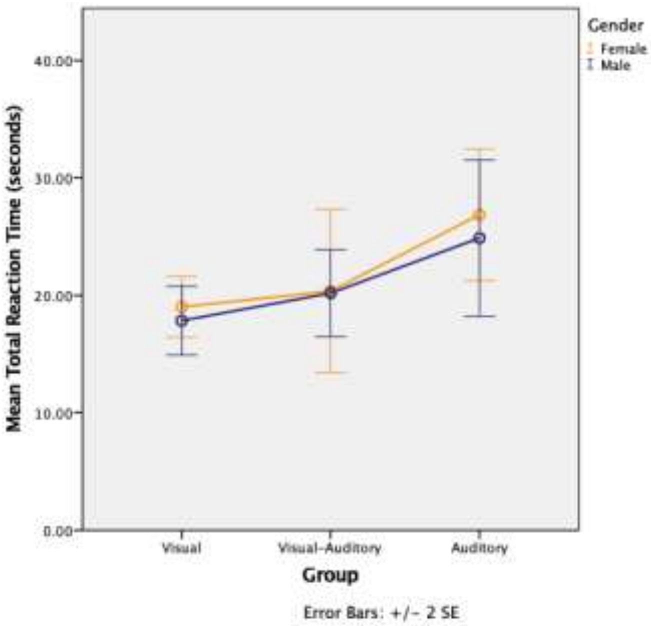


Fig. 6. Means plot of the total reaction time in seconds per gender per group

Three separate one-way ANOVA tests showed that there were also no significant differences in the total reaction time between genders in the Visual group, Welch's $F$(1.00, 12.97) = 0.36, $p$ = 0.56, *est.* $\omega^2$ -0.05, the Visual-Auditory group Welch's $F$(1.00, 9.30) < 0.01, $p$ = 0.97, *est.* $\omega^2$ -0.07, and the Auditory group, Welch's $F$(1.00, 13.62) = 0.21, $p$ = 0.66, *est.* $\omega^2$ -0.06. These outcomes are visually presented in Fig. 6.

This implies that gender had no effect on the number of errors or the total reaction time within the groups. Therefore we can state that in our study gender had no influence on navigation performance.

### E. Questionnaire

Participants were asked to rate the clarity of the provided navigational instructions on a Likert scale. These answers were transformed to numeric values, to calculate the mean within each group. The lower the mean, the more positively the participants answered (1 = Strongly Agree and 7 = Strongly Disagree).

On average, participants of the Visual group ($M$ = 2.20, $SE$ = 0.24), rated the quality of the visual instructions better than participants of the Visual-Auditory group ($M$ = 3.06, $SE$ = 0.37). The auditory instructions were rated better on average by the Visual-Auditory group ($M$ = 2.31, $SE$ = 0.22), than the Auditory group ($M$ = 3.06, $SE$ = 0.44).

Lastly, the participants of the Visual-Auditory group were asked whether they relied more on the visual or the auditory guidance. Results showed that overall the participants relied more on the auditory guidance. Moreover, none of the participants answered that they only used the visual guidance. The results described above are visually presented in Appendix III.

### F. Decision Points

As shown in Table III a total number of 53 errors were made over 11 different decision points. 28 of the 47 participants made one or more error and 24 of these participants made one or more error at decision point 5. Lastly, 10 participants made just one error at decision point 5.

TABLE III. NUMBER OF ERRORS PER DECISION POINT

| *Decision Point* | **Total** | **Visual**[a] | **Visual-Auditory**[b] | **Auditory**[c] |
|---|---|---|---|---|
| 4 | 1 | 0 | 0 | 1 |
| 5 | 24 | 1 | 12 | 11 |
| 6 | 1 | 0 | 0 | 1 |
| 7 | 3 | 0 | 2 | 1 |
| 12 | 4 | 0 | 4 | 0 |
| 13 | 4 | 0 | 1 | 3 |
| 16 | 3 | 3 | 0 | 0 |
| 17 | 7 | 0 | 3 | 4 |
| 18 | 1 | 0 | 0 | 1 |
| 19 | 2 | 0 | 1 | 1 |
| 21 | 3 | 0 | 1 | 2 |
| **Total** | **53** | **4** | **24** | **25** |

a. Number of errors of the Visual group participants

b. Number of errors of the Visual-Auditory group participants

c. Number of errors of the Auditory group participants

## V. CONCLUSION

In this study we examined the navigation performance of cyclist whilst using solely descriptive auditory route cues, in comparison to using only visual navigation instructions and using visual guidance with descriptive auditory route cues. The goal of this study was to find out if the navigation performance of cyclists improves whilst attention is divided over two sensory domains in comparison to just one domain.

Results showed that for both the number of errors and the total reaction time significant differences were present. Not only did participants make significantly more errors when descriptive auditory cues were used in the navigational instruction in comparison to solely visual guidance, but also did participants with solely auditory navigational guidance have a significantly greater reaction time. Therefore, we can conclude that the navigation performance of cyclists is negatively influenced when attention is divided over two sensory domains.

## VI. DISCUSSION

The results of the questionnaire showed that the Visual-Auditory participants overall deemed the quality of the auditory cues better than the visual instructions. Although this might seem odd, since the Visual group clearly performed better in the navigation task, we also found that participants in the Visual-Auditory group overall payed more attention to the auditory cues and less attention to the visual guidance. That could potentially explain why they valued the quality of the visual instructions lower than the auditory instructions.

Comparing these findings to the results of the statistical tests, we could also find an explanation to why the Visual-Auditory group performs worse than the solely Visual group. Since the solely Auditory group performed significantly worse than the Visual group, we can assume that the descriptive auditory routes cues had a negative effect on the multisensory information processing. This contradicts earlier findings, where multisensory information processing had a positive effect on reaction time [30].

Moreover, another interesting observation can be made by looking at the number of errors per gender between groups. Although there were no significant differences between genders in navigation performance, results showed that females in particular made less errors when there was only one source of input. In relation to earlier findings on the benefits of multisensory information processing, it could very well be that the type of sensory input was at fault.

We have specifically chosen to use descriptive auditory route cues in our study. This decision was based on earlier findings, where descriptive route cues had a positive effect on navigation performance in comparison to survey cues [12], [13]. Considering that the descriptive auditory route cues might have confused the participants, rather than reduced the need for divided attention, we could assume that the descriptive auditory cues were at fault.

This assumption could also explain why most of the errors were made at decision points without auditory route cues. Participants needed to continue straight ahead at these decision points, but decided to turn left or right. Considering that participants only payed attention to the direction of the action, but not the place of the action, it could explain why participants made the wrong decision at these points.

Furthermore, 45% of the errors were made at decision point 5. Not only was this the first decision point without a short auditory cue reminder (e.g. “Turn left), but a large proportion of the participants only made an error at decision point 5. Although we can assume that in the latter case participants learned from their mistake and payed full attention further on, one might wonder if these mistakes also would have happened when other type of auditory cues (e.g. survey cues) were used.

### *A. Limitations*

In this study we did not considered participant's chronotype, their tiredness or the time of the day of influence in our experiment. Since our study entailed an attention task, it could be that these factors may have had influence on participants' navigation performance. Moreover, participants' navigation preference was not considered in our study. However, as previous studies have shown preference of provided navigational instructions influences our navigation performance [7], [11].

Another limitation in our study entailed that the participants had no control over the virtual environment, nor over the speed and manner they cycled through an urban environment. Not only might these factors have had an influence on our experiment, but these limitations also impact the real environment experience. Our study can therefore not one on one be copied to a real environment experiment.

Lastly, no data are recorded on why participants made mistakes. Although the data might have been difficult to quantify, it could have given more insight on questions like: *Do auditory route cues only act as a cue to pay attention, rather than providing meaningful context?*

### *B. Future Research*

Future research on divided attention in relation to navigation performance is needed to get a better understanding when and how multisensory input affects our navigation performance. Moreover, it might be worthwhile to examine the effects of survey cues on navigation performance of cyclist.

## VII. Acknowledgments

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**APPENDIX I - An overview of the given auditory instructions**

Numbers correspond with the numbers in Fig. 2.

1. Turn right while facing City Hall
2. Turn right while facing the Wanamaker Building
3. Turn left at the crossing of Macy's and Greenhouse
4. Turn left at the crossing of Macy's and Sprint Bank
5. Turn right at the crossing of The Septa Transit Museum and the T-mobile store
6. Turn left at CVS pharmacy
7. Turn right at Harry's Smoke Shop
8. Turn left at the church
9. Turn left at the end of the street
10. Turn right at the parking lot
11. Cross the street into the alley and turn left at the end of the alley
12. Turn left at Arch street
13. Turn right at the crossing of the red house with dark brown windows and Linode building
14. Turn right at the crossing of Sassafras market and Wexler Gallery
15. Turn right at Fearless Athletics
16. Turn right at Elfreth's Alley

# APPENDIX II – Corsi score form

## Corsi Test

*Proefpersoonnummer:*

**Vooruit**

| *Reeks* | | *Score (0 of 1)* |
|---|---|---|
| 8 – 5 | | |
| 6 – 4 | | |
| 4 – 7 – 2 | | |
| 8 – 1 – 5 | | |
| 3 – 4 – 1 – 7 | | |
| 6 – 1 – 5 – 8 | | |
| 5 – 2 – 1 – 8 – 6 | | |
| 4 – 2 – 7 – 3 – 1 | | |
| 3 – 9 – 2 – 4 – 8 – 7 | | |
| 3 – 7 – 8 – 2 – 9 – 4 | | |
| 5 – 9 – 1 – 7 – 4 – 2 – 8 | | |
| 5 – 7 – 9 – 2 – 8 – 4 – 6 | | |
| 5 – 8 – 1 – 9 – 2 – 6 – 4 – 7 | | |
| 5 – 9 – 3 – 6 – 7 – 2 – 4 – 3 | | |
| 5 – 3 – 8 – 7 – 1 – 2 – 4 – 6 – 9 | | |
| 4 – 2 – 6 – 8 – 1 – 7 – 9 – 3 – 5 | | |

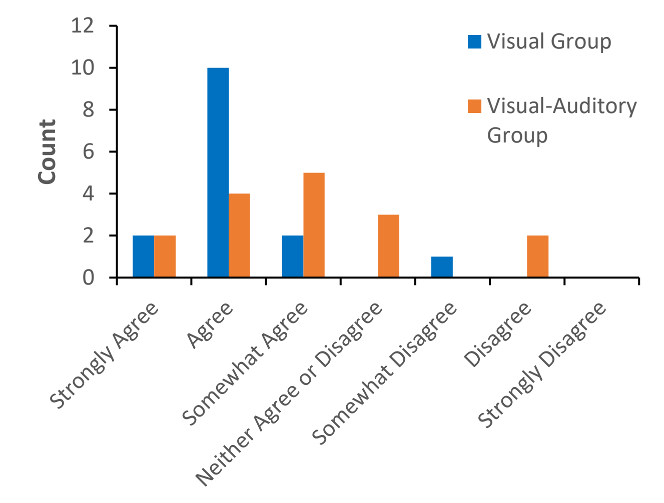
**score____________**

**Achteruit**

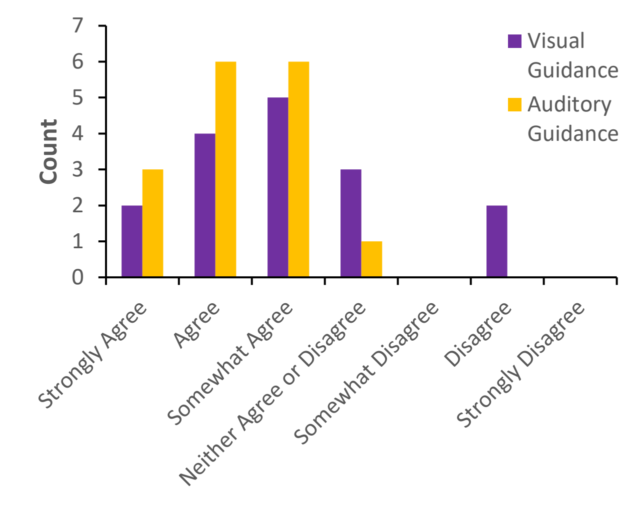
| *Reeks* | *Correct Antwoord* | *Score* |
|---|---|---|
| 4 – 7 | 7 – 4 | |
| 2 – 9 | 9 – 2 | |
| 9 – 3 – 4 | 4 – 3 – 9 | |
| 6 – 3 – 7 | 7 – 3 – 6 | |
| 1 – 5 – 2 – 8 | 8 – 2 – 5 – 1 | |
| 7 – 4 – 3 – 9 | 9 – 3 – 4 – 7 | |
| 3 – 1 – 8 – 6 – 5 | 5 – 6 – 8 – 1 – 3 | |
| 9 – 3 – 1 – 4 – 7 | 7 – 4 – 1 – 3 – 9 | |
| 2 – 8 – 3 – 5 – 6 – 4 | 4 – 6 – 5 – 3 – 8 – 2 | |
| 5 – 3 – 1 – 2 – 8 – 9 | 9 – 8 – 2 – 1 – 3 – 5 | |
| 7 – 3 – 2 – 9 – 1 – 8 – 6 | 6 – 8 – 1 – 9 – 2 – 3 – 7 | |
| 4 – 3 – 7 – 6 – 2 – 5 – 9 | 9 – 5 – 2 – 6 – 7 – 3 – 4 | |
| 1 – 9 – 6 – 3 – 5 – 4 – 2 – 9 | 9 – 2 – 4 – 5 – 3 – 6 – 9 – 1 | |
| 2 – 9 – 4 – 6 – 1 – 7 – 3 – 5 | 5 – 3 – 7 – 1 – 6 – 4 – 9 – 2 | |

**score____________**

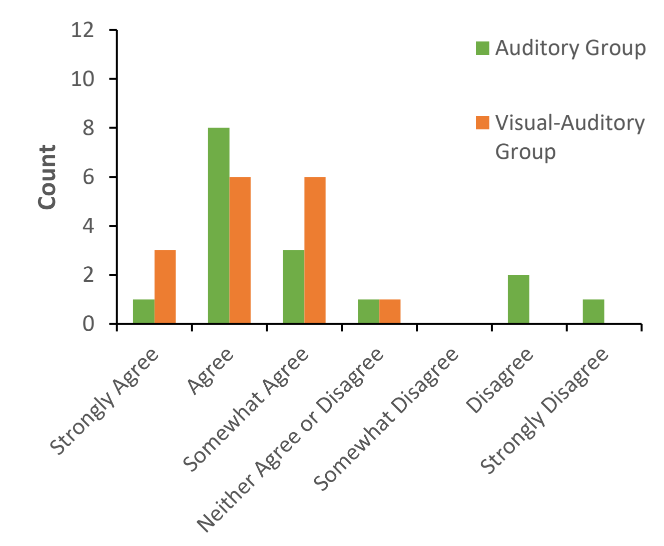
# APPENDIX III – Results of the Questionnaire on the Quality of the Navigation Instructions



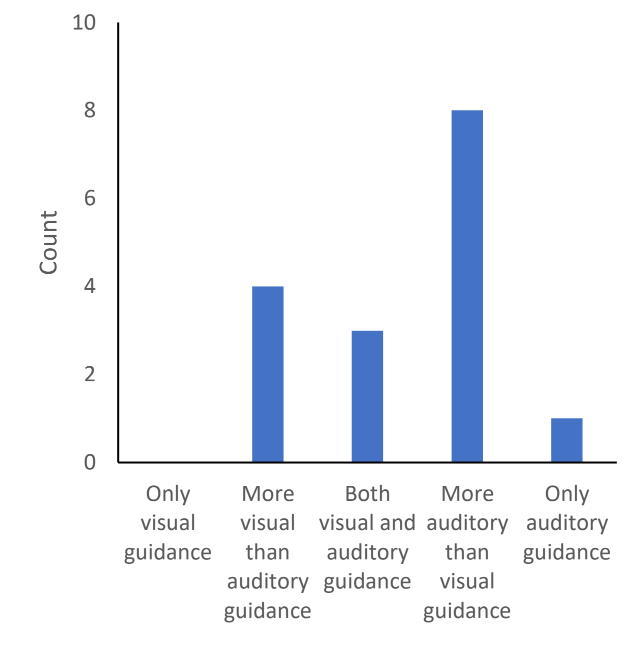

Participants' answers on clarity of visual navigation guidance




Group Visual-Auditory participants' answers on clarity of navigation guidance.




Participants' answers on clarity of auditory navigation guidance




Group Visual-Auditory participants' answers on type of navigation usage during the experiment