Bicycle navigation and eye fixations

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Abstract

Turn-by-turn Google maps navigation was compared to turn-by-turn auditory Google maps navigation, Beeline as-the-crow-flies navigation, and turn-by-turn printed textual navigation. Through a convenience sample data from 30 participant have been gathered. Participants completed a navigational task in Vinkhuizen, Groningen, four times, with a different device in each part. As measured by eye-fixations, auditory turn-by-turn navigation imposed a smaller visual workload demand than regular google maps turn-by-turn navigation. The audio instruction did not require visual attention; however, the auditory navigation was not preferred due to technical difficulties, the absence of a replay option and insufficient audibility participants experienced. Contrary to expectations, turn-by-turn google maps navigation was not more visually demanding than as-the-crow-flies navigation. Also printed textual turn-by-turn navigation was not more visually demanding for the cyclist than turn-by-turn google maps instructions.

Keywords: visual workload, bicycle navigation, eye-fixations

Bicycle navigation and eye fixations

Cycling as a method of transportation has over the years become more and more popular for many reasons. It saves money that would be spent on fuel when using a car for travelling and using a bicycle is much more environmentally friendly than travelling by car or other fuelled vehicles. Furthermore, cycling has become more comfortable over the years with the development of better bike-designs, comfortable seats and handlebars and the development of methods to easily navigate when travelling on a bicycle. Bicycle navigation became especially advanced with the development of the mobile phone. Many apps, such as Google Maps, have been designed since to be used as navigational aids during cycling.

In the Netherlands from 2019 the use of handheld mobile phones during cycling has been forbidden by law. The only way to currently use a mobile device during cycling is when it is attached to the handlebar, for handsfree use or to connect headphones or earbuds to the device, to make use of auditory navigational instructions for example. A study from De Waard et al. (2013) showed that the use of a mobile device for navigational reasons could have the same detrimental effects on cycling safety as receiving text messages. In a study from De Waard et al. (2011) it was also found that even when mobile devices are used handsfree they still require significant mental effort during cycling. It is therefore important to research how safe the use of navigation devices while cycling is.

In the present study a few of the most common navigational methods for cyclists will be compared where eye fixations were determined to describe mental workload during bicycle navigation tasks.

Mental workload

According to De Waard (1996) mental workload is the interaction between task demands placed upon a person and the capacities of that person. This description of mental workload is very relevant in the context of traffic safety because of the additional stimuli that accompany modern cycling, such as navigational devices and phones. In research from Li et al. (2020) many drivers have reported they found complex navigational systems to be mentally and cognitively distracting while driving. This poses a threat to cyclist traffic safety as the added mental and cognitive load of navigating during cycling could exceed their mental capacities and potentially cause accidents.

A useful model to describe performance of a person while driving is proposed by Michon (1971, 1985) and Janssen (1979). This model states that driving can be organized as a complex task with 3 task-levels that are executed alongside each other: the strategic level, the manoeuvre level and the control level. This model was originally made for car driving, but these principles can be extended to cycling as well. The strategic level represents choices that are made around the cycling, for example the route that will be taken and which navigational aids will be used while cycling. The manoeuvre level can be understood in terms of reacting to in-the-moment events. Such events can be upcoming traffic, anticipating behaviour of others and other environmental situations. And lastly the control level which encompasses the motoric-control processes of cycling. Braking, pedalling, steering and balance are amongst these processes, as well as lateral-position control. Lateral-position control is, in the cycling context, the ability to stay on the right-hand side of the road and not hit the curb.

As mental workload results from a combination of task demands and operator capacities, if these demands are high and ask for many processing resources to be used mental workload will increase. During cycling some of these processing resources include visual processing, auditory processing and motor skills. While cycling, cyclists are watching their environment and the traffic around them, as well as noticing passers-by auditorily and using their motor skills for the actual cycling. Assessing mental workload is essential for establishing when mental and cognitive load may cause a deterioration in performance, especially when aside from cycling, navigation is also attempted. With such information conclusions can be drawn about the safety of popular modern navigational methods for cycling.

De Waard (1996) states that when measuring mental workload, the use of multiple measures is needed to accurately consider mental workload. In past studies three different groups of measures have often been used to measure mental workload: self-reports to measure subjective mental effort, physiological measures including eye fixations, and task performance parameters (de Waard, 1996). Whereas mental effort is an intentional process where someone voluntarily controls how much mental energy they allocate to a task, mental workload as mentioned earlier results from an interaction between the person and their environment (Brookhuis & de Waard, 2009). The use of measures such as subjective mental effort self-reports then only partly cover the concept of mental workload. Therefore, in the present study the focus lies on eye fixations as a measure to capture mental workload. Many studies have, amongst other measures, used eye fixations to determine mental workload while driving. For example, in a study of Van Lopik et al. (2020) eye movements were recorded to determine fixations in gaze behaviour during driving. Visual attention is an important resource during traffic participation. The use of eye-fixations as a measure of mental workload is therefore important because from that, data such as the percentage of time that was fixated on a navigation device can be calculated. When a person’s visual attention is fixated on a navigation device it cannot be completely used for keeping track of their environment and traffic participation. This poses risks to the traffic safety of the cyclist and of others around them.

Navigational methods

Many new navigational devices and apps have been developed over the years. A popular navigational system currently is Google Maps. It contains many functions for different vehicles and pedestrians and, as most people have a smartphone, the free app is very accessible. Google Maps can also be used in auditory mode, where the instructions are presented auditory. Alternatives such as paper maps still exist but have become quite outdated due to the many technological options. New navigational devices have also been brought onto the market, such as the Beeline device (Savino et al., 2020). Beeline works much like a compass to guide you in the direction of your chosen endpoint.

Most of these navigational systems are based on Turn-by-turn navigation (TBT). Google Maps, and printed instructions are forms of TBT navigation. With Google Maps there is a large visual component because it shows the user’s current location, the route that it suggests, and it presents when to take turns. With printed instructions this visual component is less extensive as it mostly shows written instructions, and the distance until a turn. Another navigational method is As-the-crow-flies navigation (ATCF). Beeline is an example of an ATCF navigational system. As mentioned earlier, this functions like a compass and points you in the general direction of your chosen destination. The user is completely free to decide which turns to take and is able to see if they are nearing their destination with the number of meters or kilometres below the compass arrow, which counts down as they get closer.

In the present study the navigational methods Google Maps, Google Maps in audio mode, Beeline, and printed textual instructions were used. The printed textual instructions were generated from Google Maps. Google Maps, Beeline and the printed textual instructions all present visual information. Only the Google Maps in audio mode presents auditory information. This difference is expected to be seen in the results of this research because of all the navigation devices used, the Google Maps auditory information will not interfere with the visual attention during cycling in the way that the other devices do. This is expected here because the participants essentially do not need to take their eyes off the road during cycling to receive the navigation instructions whereas with the other devices they do. Furthermore, it is expected that the printed textual instructions will be more mentally demanding than the Google Maps visual instructions because of the way the visual information is presented. It is expected that textual information takes longer to fully process and remember correctly until the instruction needs to be executed than a visual representation of the entire route and point of current location.

Research question and hypotheses

In the present study eye fixations were determined to compare visual attention and mental workload of cyclists using different navigational methods during cycling. Comparisons were made between Google Maps visual TBT navigation and auditory Google Maps TBT navigation, Google Maps visual TBT navigation and the Beeline ATCF navigation, and Google Maps visual TBT navigation and printed textual instructions TBT navigation. For these comparisons the following hypotheses were formulated:

Hypothesis 1 (H1): Navigational methods based on TBT instructions such as visual Google Maps are less mentally demanding than ATCF navigation devices such as the Beeline.

Hypothesis 2 (H2): Auditory TBT instructions are less mentally demanding than visual Google Maps TBT instructions.

Hypothesis 3 (H3): Printed textual TBT instructions are more mentally demanding than more complete visual TBT instructions such as in Google Maps.

Material and methods

Participants

Following approval of the study through the university ethics committee (PSY-2122-S-0279), 30 participants were recruited through a convenience sample. The participants were predominantly young, with a mean age of 24.7 (SD = 5.68). The youngest participant was 19 and the oldest was 43. Amongst these participants 63% identified as male, 26% as female, and 10% as non-binary. Of the participants 57% had the Dutch nationality and the other participants had non-Dutch nationalities such as American, German, Chinese and Indonesian. Participants were not paid for participation and had the opportunity to draw back from the experiment at all times without having to give an explanation.

Experimental setup

The experimental protocol that was chosen was a field experiment in which all sessions were completed between April and May 2022 on dry days outside, during daylight hours. The experiment was a within-subjects design. The experiment was set in Vinkhuizen, Groningen. Prior to joining the experiment, the participants all received an email containing information about the experiment and the informed consent from. After signing informed consent at the location of the experiment, the participants completed questions about their demographics and familiarity with the area of the experiment and their cycling experience. The experiment was then introduced to the participants through a scripted introduction to reduce variation in starting experience as much as possible. Participants used their own bicycles during the experiment to avoid having to get used to an unfamiliar bicycle. During the participant-instruction the camera that would be used to film the participants' eye movements was applied to the handlebar, along with the other devices needed for the first task. Image 1 shows the printed textual instructions that were used in the experiment. Image 2 shows the Beeline interface. Image 3 shows the Beeline when attached to the handlebar. Image 4 shows the camera attached to the handlebar. Image 5 shows the iPhone when attached to the handlebar. Image 6 shows the earbuds that were used in the auditory condition. The same iPhone was used during the entire experiment to access Google Maps as a navigational method. The participants had the opportunity to ask any questions they might have about the device, task or anything regarding the experiment and were able to voice any concerns they might have had.

Image 1

Printed textual instructions

Image 2

The Beeline device

Image 3

The Beeline device attached to the handlebar

Image 4

The camera that was used during the experiment

Image 5

The black phone is the iPhone used during the experiment

Image 6

The earbuds used during the audio condition

Experimental stimuli

The participants were asked to complete a route, consisting of four parts in which they completed a navigation task with a different navigational device for each part. The use of the different devices during the tasks was balanced in order to reduce any sequence effects. The participants all completed the same route but used different navigational devices per part. The four parts of the route each were a mean distance of 1.5 kilometres with a minimum distance of 1.2 kilometres and a maximum distance of 1.8 kilometres. For images of the routes displayed in Google Maps see Appendix A. After completion of each part of the route the participants filled out a short questionnaire about their experience of the task they had just completed. At the end of the complete session participants also filled out a final questionnaire about the whole experiment and their navigational preferences. During the cycling tasks participants were followed by one of the experimenters at about three meters behind, to not interfere with the sessions. The follower intervened if participants had deviated from the intended routes for more than five minutes and were not correcting themselves in any way.

Furthermore, the follower timed the time of completion for each part of the route, making use of a stopwatch. The follower was also present to rectify any issues with the devices if necessary and to always ensure participant safety.

Measures

Speed

Speed was measured with use of the Contour+2 camera GPS-data. The time of completion for each part of the route that was timed by the follower during the sessions was used as a back-up to generate speed-data from. GPS-data were converted through use of the Contour Storyteller program (version 3.6.2.1043), exported into text files and imported into Microsoft Excel. Speed was then calculated by division of the optimal route distance of each part by the participants' time of completion of that part. This resulted in speed in terms of metres per second.

Subjective mental effort

After completion of each part of the route, participants were asked how much mental effort they had to invest in the cycling tasks. For this the Rating Scale Mental Effort, RSME, was used (Zijlstra, 1993). The RSME is a unidimensional scale consisting of a rating scale from 0 to 150. At irregular intervals there are set points of mental effort. A rating of 2 indicates 'no effort', a rating of 37 indicates 'some effort', 85 indicates 'great effort' and 112 indicates 'extreme effort'. Participants indicated their ratings on this scale by crossing the point they felt best represented their experienced mental effort. Along with this measure frustration was also rated with a similar rating scale, to separate frustration from mental effort (van Acker et al., 2018). The results of these ratings are reported in Anema (2022).

Rating of navigational methods

After completion of the entire route the participants were also asked to fill out a questionnaire about the navigation devices that were used. They were then able to rate the devices on a scale from 1 to 10. One indicating they did not like the navigation device very much, and 10 meaning they really liked the navigation device. They were also asked what navigational methods they would most likely use in the future.

Eye Fixations

During this experiment eye fixations were measured in a way similar to how it was done in earlier research from De Waard et al. (2017) via use of a Contour+2 camera that was attached to the handlebar during the cycling tasks. Through the video content that was recorded, data such as the frequencies and durations of eye fixations on the navigational method during cycling was calculated. Per condition a 1-minute representative segment was selected. The video content was imported into the program Handbrake to cut the specific fragments that were used for each participant in each condition. These fragments were then imported into ELAN (version 6.3) to be analysed. The eye fixations were marked manually and through these annotations the duration of the fixations was calculated.

Results

Descriptive analysis

First the self-reported familiarity data were assessed which showed that 87% of participants used their bicycle as a means of transport at least four times a week. When they use their bicycle, participants reported that they often used it for a duration of 10 minutes (33.3%) or for a duration of 15 minutes (36.7%). Of participants 77% also reported that cycling was their primary transportation choice. Of participants 70% had at some point used a navigational device during cycling. The most popular and used navigational method for these participants was Google Maps as a visual navigational method. However, they did not use it often, 50% of participants used navigational aids less than once per week, and 30% of participants used it once per week. With regards to the familiarity with the area of the experiment, Vinkhuizen, 80% of participants reported they were not, or only a little bit familiar with the area.

Data from 9 of the 30 participants were missing. In the analyses these participants were excluded. A substantial sample with complete data remained, consisting of 21 valid cases. To analyse the data a Repeated-Measures Analysis of Variance was applied (ANOVA).

Means and correlations

The mean frequencies, mean durations, mean total durations, mean percentages of fixations and mean speed are displayed in Table 1.

Table 1

Mean frequencies, mean durations, mean total durations, mean percentages of fixations on the device and mean speed

	Mean **frequency** of fixations per second (st. dev.)	Mean **durations** of a fixation (in seconds)(st. dev)	Mean duration of **total fixation time** (in seconds)(st. dev.)	Mean **percentage** of fixation time (st. dev.)	Mean **speed** (metres per second) (st. dev.)
Visual Google Maps TBT	6.87 (3.43)	1.18 (0.36)	8.23 (3.87)	13.80 (6.40)	4.35 (0.90)
Auditory Google Maps TBT	0.21 (0.83)	0.07 (0.24)	0.19 (0.82)	0.35 (1.50)	4.21 (0.65)
Beeline ATCF	9.17 (3.37)	0.97 (0.30)	8.66 (4.04)	14.58 (6.80)	3.91 (0.59)
Printed textual TBT	4.70 (2.29)	1.79 (0.77)	8.92 (5.83)	14.93 (9.80)	3.65 (0.68)

Rating results of navigational methods

The results of the end ratings of the different navigation devices are displayed in table 2. Detailed results and analyses are reported in Anema (2022).

Table 2

Navigation device ratings per condition

	Preference end ratings M
Google Maps (TBT)	8.38 (1.13)
Google Maps Audio (TBT)	5.75 (2.50)
Beeline (ATCF)	6.00 (2.07)
Printed textual instructions (TBT)	4.07 (1.55)

Note: M = mean; Preference end ratings are on a scale of 1 to 10.

RSME results

The results of the RSME questionnaire are displayed in table 3. Detailed results and analyses are reported in Anema (2022).

Table 3

Subjective mental effort ratings per condition

	Mental effort M (st. dev.)
Visual Google Maps (TBT)	27.27(17.91)
Google Maps Audio (TBT)	46.00(28.71)
Beeline (ATCF)	50.20(29.39)

Printed textual instructions (TBT)	65.55(26.11)

Note: M= mean; Mental effort ratings are on a scale of 0 to 150.

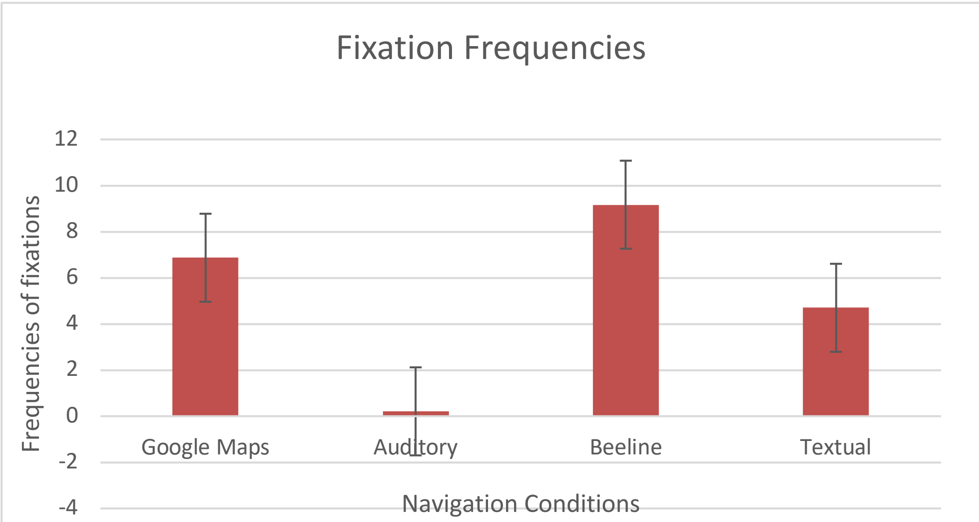
Hypothesis testing

Visual workload - frequencies

The results of the fixation frequencies are displayed in figure 1. In the textual condition the lowest number of fixations was found, while in the beeline conditions the highest number of fixations was found. The Google Maps condition is in between the other conditions. The auditory condition shows only a few fixations. To test these differences a *Repeated-Measures ANOVA* was applied. Assumptions were not violated (Appendix C). Significant differences between the conditions were found (F(50.414), p = .001, $\eta^2 = 0.716$). To test the first hypothesis pairwise comparisons were performed. Google Maps was compared to the Beeline condition. In terms of frequencies the hypothesis was not supported. In the Google Maps condition there were not significantly less fixations than in the Beeline condition (Mean difference I-J = -2.38, a = 0.05, p = 0.11, sd = 0.92). The second hypothesis was also tested with pairwise comparisons. Google Maps was compared to the Auditory condition. In terms of frequencies the hypothesis was supported. In the Google Maps condition there were more fixations than in the Auditory condition. This difference was significant (Mean difference I-J = 6.24, a = 0.05, p = 0.001, sd = 0.73). The third hypothesis was also tested with pairwise comparisons. The printed textual condition was compared to google maps. In terms of frequencies the hypothesis was not supported. In the printed textual condition there were less fixations than in the Google Maps condition. The difference was significant (Mean difference I-J = 1.476, a = 0.05, p = 0.001, sd = 0.73).

Figure 1

Number of fixations per condition per minute



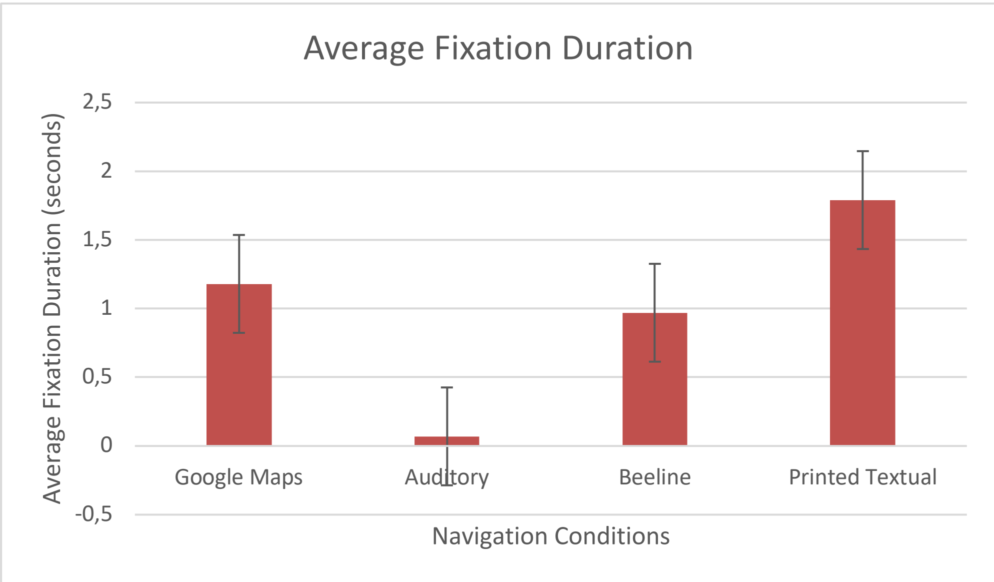
Note: error bars display the standard error.

Visual workload - average duration

The results of the average duration of a fixation per condition are displayed in figure 2. The printed textual condition shows on average the longest fixation. The few fixations in the auditory condition are on average the shortest. In the beeline condition shorter fixations were found than the Google Maps condition. To test if differences were significant a *Repeated-Measures ANOVA* was applied. The sphericity assumption was violated so the Greenhouse-Geisser correction was applied (Appendix B). Significant differences were found between the conditions (F(73.7), $p = 0.001$, $\eta^2 = 0.787$). For all of the hypothesis testing again pairwise comparisons were used. Google Maps was compared to the Beeline condition. In terms of the duration of the average fixation the first hypothesis was not supported. The average fixation duration was not statistically significantly longer in the Beeline condition than in the Google maps condition (mean difference I-J = 0.183, a = 0.05, p = 0.262, sd = 0.09). Support for the second hypothesis was found. The average fixation duration in the Google Maps condition was longer than in the Auditory condition. The difference was also found significant (mean difference I-J = 1.115, a = 0.05, p = 0.001, sd = 0.106). No support was found for the third hypothesis. The average fixation duration in the textual condition was shorter than in the google maps condition. This difference was also found to be significant (mean difference I-J = -0.695, a = 0.05, p = 0.001, sd = 0.142).

Figure 2

Average duration of a fixation per condition.



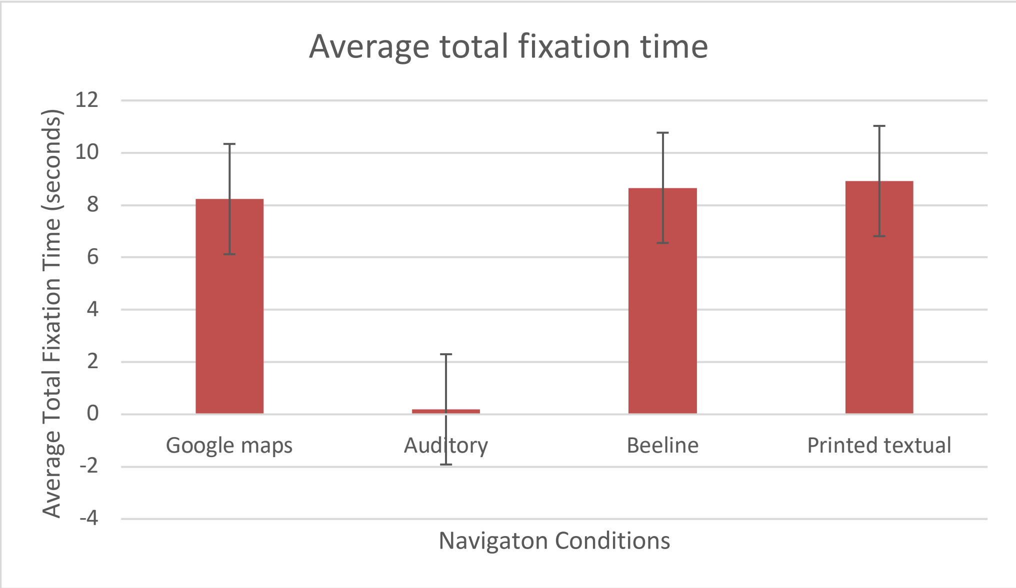
Note: error bars display the standard errors.

Visual workload – average total fixation time

The results of the average total fixation time are displayed in figure 3. In the printed textual condition, the longest total fixation time was found. In the beeline condition and in the google maps condition similar total fixation times were found. In the auditory condition the shortest total fixation time was found. To test if the differences between the conditions were significant a *Repeated-Measures ANOVA* was applied. Assumptions were not violated (Appendix B).

Figure 3

Average total fixation time (s) per condition.



Note: error bars display the standard errors.

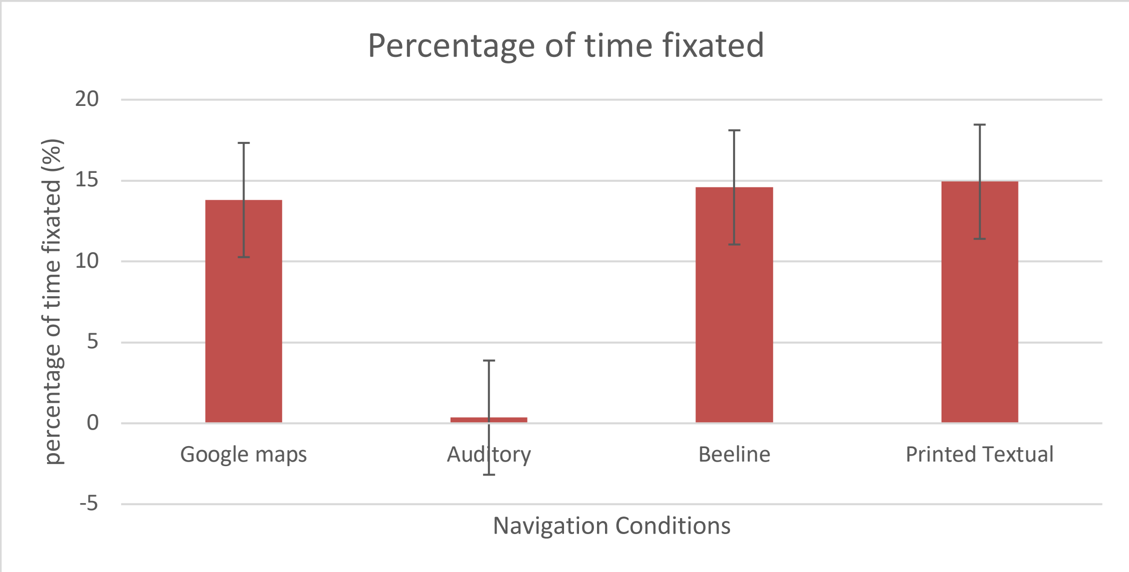
Significant differences were found between the conditions (F(26.684), p = 0.001, $\eta^2 = 0.572$). For all the hypothesis testing pairwise comparisons were applied. For the first hypothesis in terms of total fixation time no support was found (mean difference I-J = -0.982, a = 0.05, p = 1.000, sd = 1.328). Support was found for the second hypothesis. In the Google Maps condition a longer total fixation time was found than in the auditory condition. This difference was found significant (mean difference I-J = 7.735, a = 0.05, p = 0.001, sd = 0.903). The third hypothesis was not supported. In the printed textual condition no longer total fixation time than in the Google maps condition was found (mean difference I-J = -1.583, a = 0.05, p = 1.000, sd = 1.453).

Visual workload – Percentages

The results of the percentages of eye fixations are displayed in figure 4.

Figure 4

Percentage of time fixating on the navigation device per condition.



Note: error bars display standard errors.

In the printed textual condition the highest percentage of time fixated was found. Then in the beeline condition a little less percentage of time fixated was found, and in the google maps condition a lower percentage of time fixated was found than in the beeline condition. In the auditory condition the lowest percentage of time fixated was found. To test if these differences were significant a *Repeated – measures ANOVA* was applied. Assumptions were not violated (Appendix B). Significant differences were found between the findings in these conditions (F(26.750), $p = 0.001$, $\eta^2 = 0.572$). To test the hypotheses pairwise comparisons were applied. No support was found for the first hypothesis. After comparison of the Beeline condition to the Google Maps condition no significant difference in the percentage of time fixated was found (mean difference I-J = -1.700, a = 0.05, p = 1.000, sd = 2.236). Support was found for the second hypothesis. In the Google maps condition a much higher percentage of time fixating on the device was found than in the auditory condition. The difference was found to be significant (mean difference I-J = 12.948, a = 0.05, p = 0.001, sd = 1.508). No support was found for the third hypothesis. After comparison of the printed textual condition with the Google Maps condition no significant difference in percentage of time fixated was found (mean difference I-J = -2.619, a = 0.05, p = 1.000, sd = 2.423).

Discussion

In this study different navigational methods were compared with regards to the visual mental load they generated while cycling. Specifically, eye fixations were determined to see how the participants fixated on the navigational devices. Compensatory behaviours were also assessed, such as cycling speed. Participants lowered their cycling speed to compensate for having to fixate more or longer on the navigation devices and this was also taken into account in the evaluation of the results. The first hypothesis of this study stated that it was expected that navigation based on TBT instructions, such as visual google maps would be less mentally demanding than ATCF navigation, such as the beeline. None of the eye fixation measures provided support for this hypothesis. The TBT navigation was not significantly rated subjectively less mentally effortful or a more preferred method of navigation. Furthermore, with the second hypothesis expectations were that auditory TBT instructions would be less mentally demanding than visual google maps TBT instructions. In terms of eye fixations this hypothesis was supported by all the measures. This result could be explained by the fact that auditory instructions make use of different processing resources than visual instructions. So, because of the auditory presentation of the instructions, vision did not need to be split up between navigating and the cycling and environment. The last hypothesis stated that it was expected that printed textual TBT instructions would be more mentally demanding than more complete visual TBT instructions such as google maps. None of the eye fixation measures however, supported this hypothesis.

Taken together, the eye fixation measures showed that for the printed textual instructions participants fixated less frequently on the instructions, but per fixation for a longer time. This could be explained by the reading task taking longer, but then being better remembered after a single longer fixation, instead of eliciting multiple short fixations. The latter was the case for the beeline condition. Participants did not fixate on the device for long periods at a time, but they did fixate on the device with a higher frequency. This could be explained by the nature of the interface of Beeline. Because of the compass-mode there is not much visual information to take in, so the fixations do not need to be lengthy. However, because people are free to take whichever turn they want with the beeline device, it elicits frequent checking to see how the arrow changes in relation to the destination and to see if the distance is still counting down. The Google maps visual condition sat in between the other conditions in terms of all the eye fixation measures. This could be explained by the auditory condition not requiring any fixations in principle, and Google maps being the most popular navigational method, therefore due to familiarity scoring lower on the eye fixation measures.

All in all, the different conditions do not differ much in terms of visual workload, with exception of the auditory condition. The auditory condition did not require visual attention due to the instructions not being visual, but even so this was not the most preferred navigation device, as mentioned earlier. While completing the questionnaire after the entire route the participants also had the opportunity to leave any comments about their experience they wanted to add. Some participants reported they felt a lag between the audio instruction and their position on the route which they reported to be confusing. Participants also reported that this made them feel less confident about whether they were cycling the intended route correctly.

In table 1 in the results section the average speed per condition was also reported. It was found that cycling speed was the highest in the google maps condition. This could again be explained by google maps being the most popular navigation device, and so due to familiarity the participants felt more experienced and confident with this device and therefore cycling faster. In the auditory condition a lower cycling speed was found, which could be explained by the technical difficulties the participants reported about this condition. An even lower cycling speed was found in the beeline condition. Here, participants could be compensating for having to look for, and choose, which turn they would take at any given moment. The lowest cycling speed was found in the printed textual condition. It is possible that the task of reading and understanding textual instructions during cycling made the participants slow down as this took their visual attention away from the road for longer durations and they compensated by reducing their cycling speed.

Strengths of this study

Whereas in earlier research, such as De Waard et al. (2017), comparisons were mostly made with a paper map condition, in this study a (visual) Google maps condition was used. This navigational system is more representative of what people currently use amongst modern navigational methods, and this narrows down the differences for the conditions that are being compared.

The within-subjects design of this study, combined with a balancing of conditions, really protected against influence of individual differences on the results. The sample size of 30 was also larger than in earlier research, for example in De Waard et al. (2017).

Limitations

The sampling in this study was done through a convenience sample of friends and acquaintances of the experimenters. This may have compromised the representativeness of the sample, due to most participants being students with a low average age. This may not be representative to the average cyclist. Furthermore, these participants completed the cycling tasks purely because they entered an experiment, and not for any true navigational purposes. This may have affected the results. Lastly, the location of the experiment gave it a specific scope. The neighbourhood that was used to conduct the experiment in was the area Vinkhuizen in Groningen. This area was built very block-wise with many straight streets and a low traffic-volume on average. Most streets did not have a designated cycling lane, and there were no curving roads. This was chosen to ensure participant safety, and to enlarge the chance that participants would be unfamiliar with the area. Results might have been very different if the experiment had been conducted in the city centre, for example. For ethical and safety reasons it was not responsible to conduct the experiment in such a busy area.

Implications for further research

Interesting areas for future research, based on the limitations of this study would be to conduct the experiment in a different location to see how that could change the results. For example, in a city centre or in different weather conditions as our sessions were only held on dry days outside during daylight hours, as mentioned earlier. Also, the use of a different incentive for the participants might change the way they completed the navigational tasks. If they were to receive a payment for this their behaviours could be different during the cycling. This could mimic the natural goal of having to be at a destination in a certain amount of time.

Conclusion

In this research different navigational methods were compared with regards to eye fixations to reflect visual workload during bicycle navigation. It was found that navigational methods based on TBT instructions, such as google maps were not significantly less mentally demanding than ATCF navigation devices such as beeline. Furthermore, it was found that auditory TBT instructions were significantly less mentally demanding than visual google maps TBT instructions. This was explained by the visual resources during cycling not having to be divided between navigation and cycling because the navigation was done auditorily. However, this was not the most preferred navigation device due to the participants being dependent on the audio instructions being timed correctly, which they reported was not always the case. And lastly it was found that printed textual TBT instructions were not significantly more mentally demanding than more complete visual TBT instructions such as in google maps.

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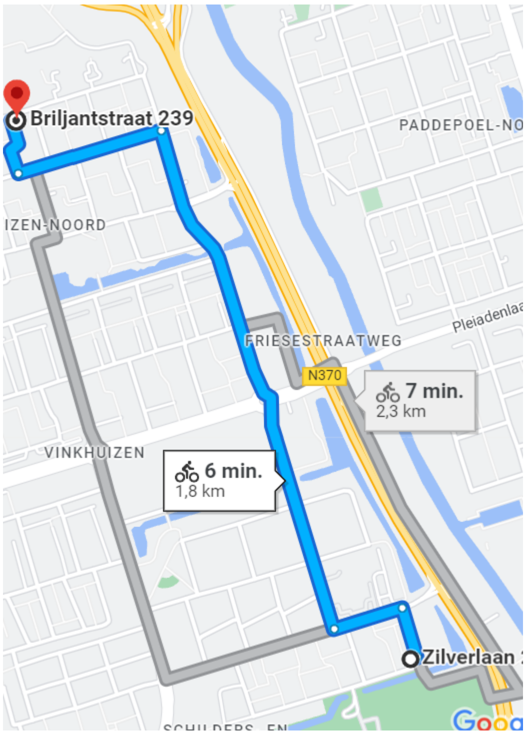
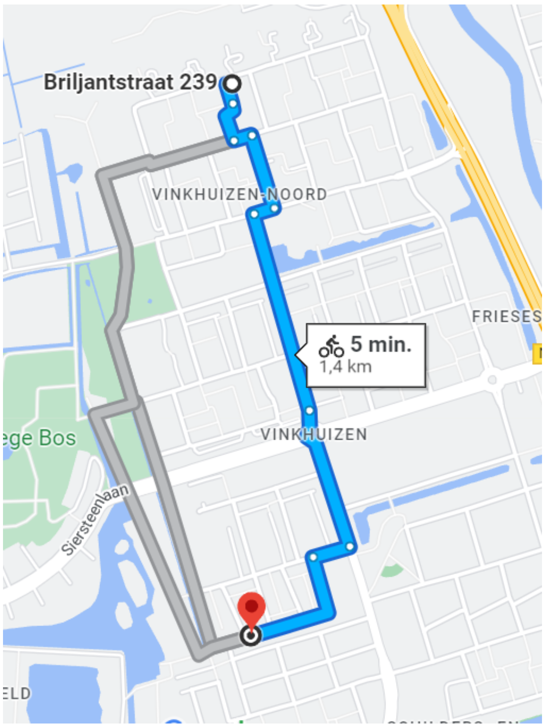
Appendix A

Maps of the four parts of the route

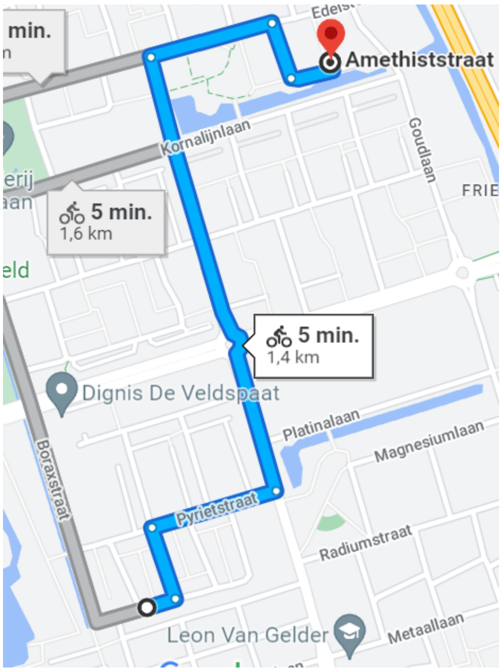
Ideal route for segment 1



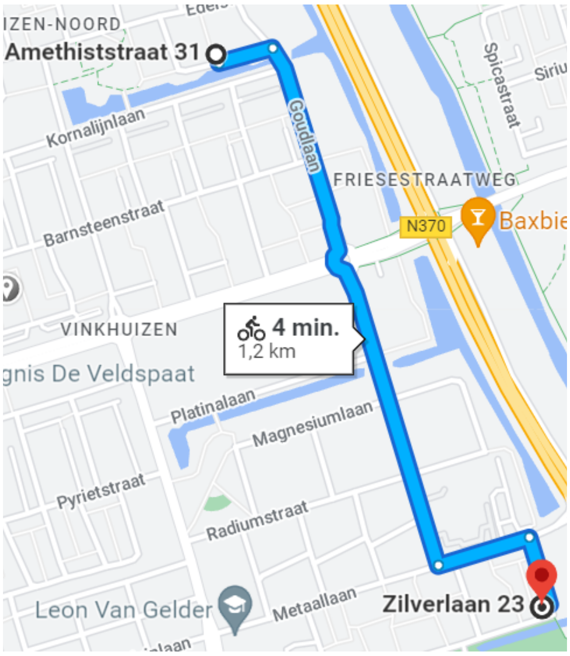
Ideal route for segment 2



Ideal route for segment 3



Ideal route for segment 4



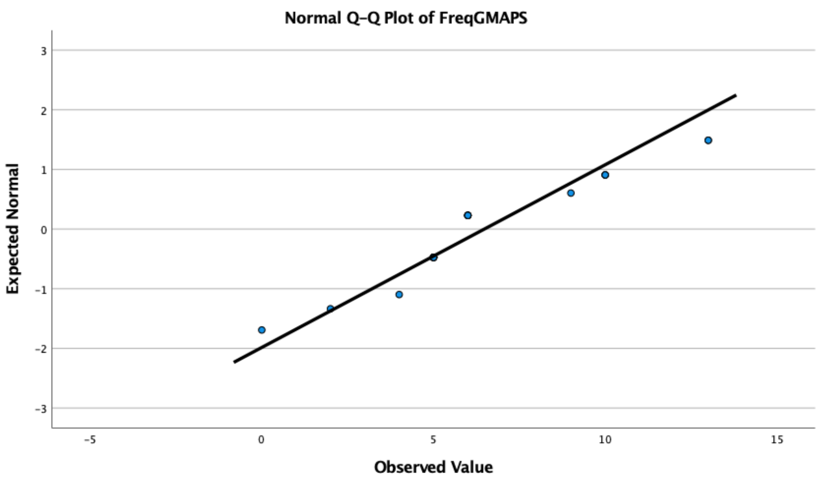
Appendix B

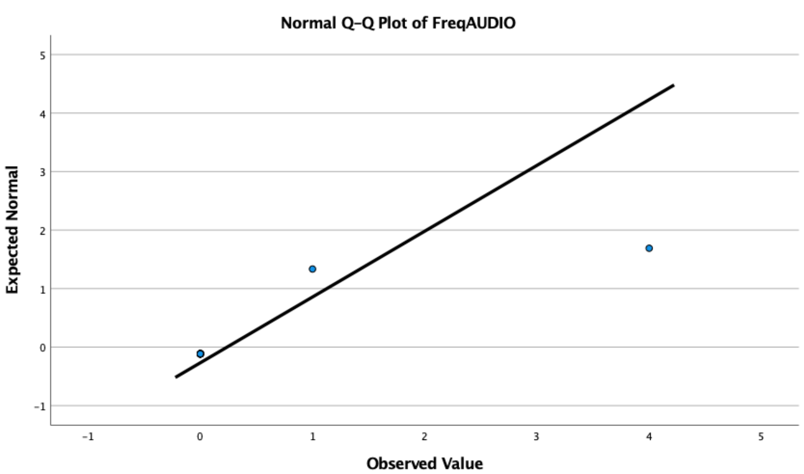
Assumptions of normality were checked with Q-Q-plots and sphericity was checked with Mauchly's test of sphericity. For the average duration the sphericity assumption was violated so the Greenhouse-Geisser correction was applied there.

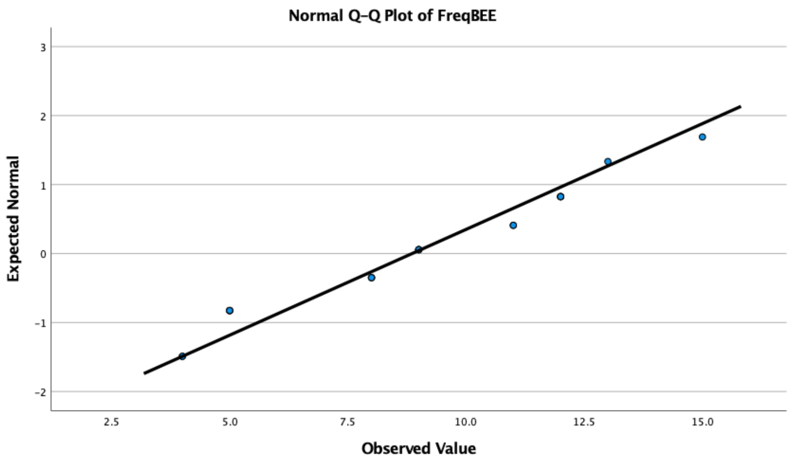
Eye Fixations

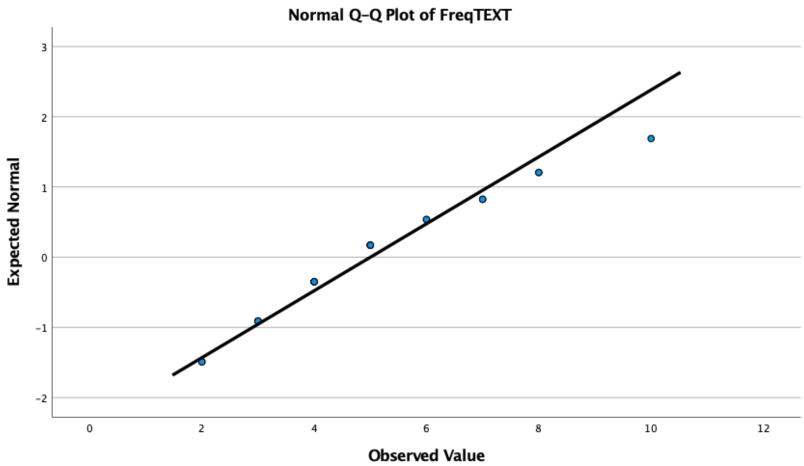
Frequencies

The assumption of sphericity was not violated for the frequencies ($\chi^2 = 7.87$; $p = 0.164$).





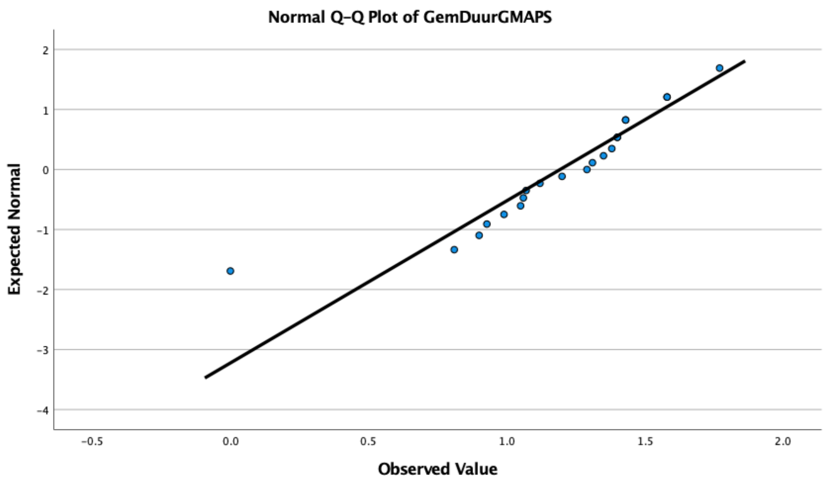


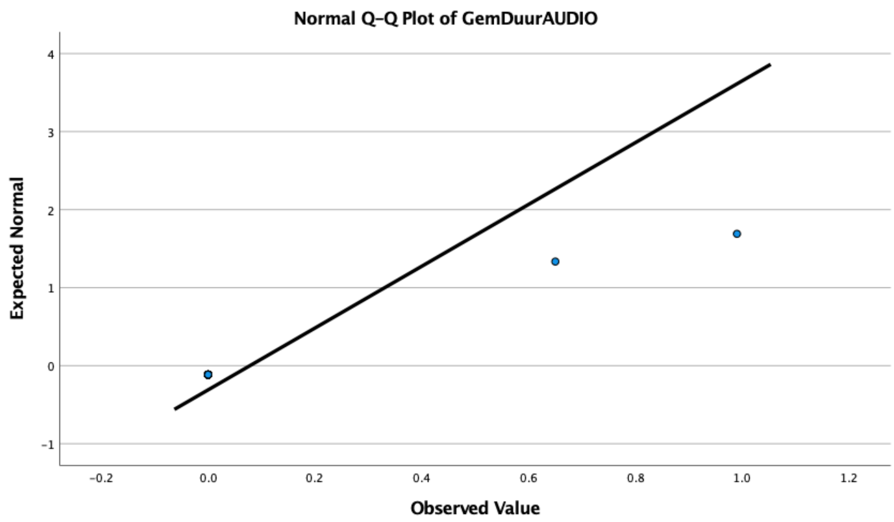


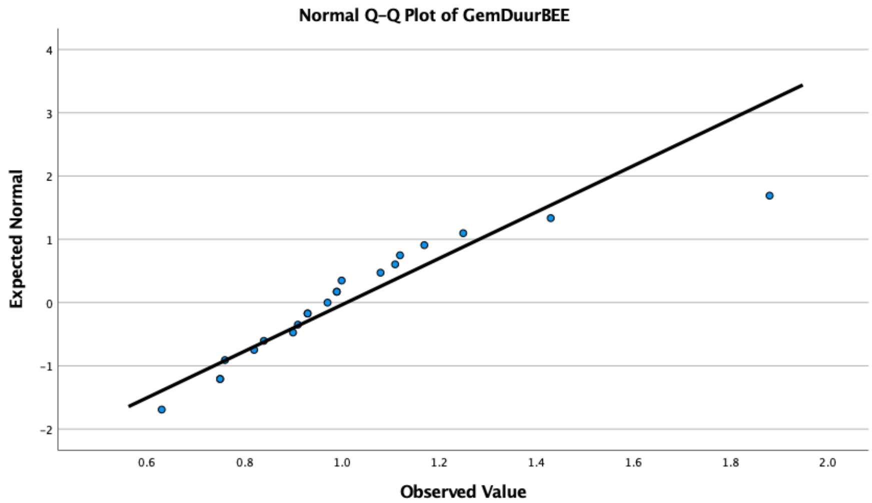
Average duration

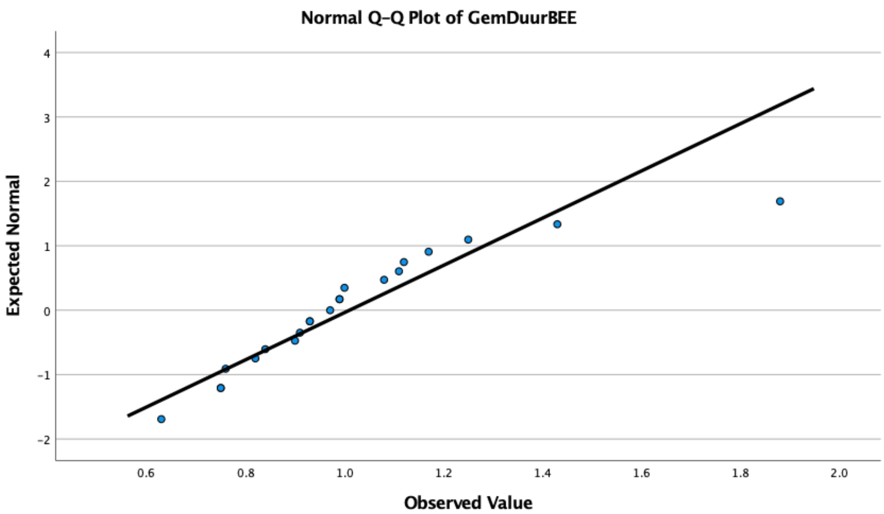
The assumption of sphericity was violated for the average duration ($\chi^2 = 13.748$; $p = 0.017$)

The Greenhouse-Geisser correction was applied.



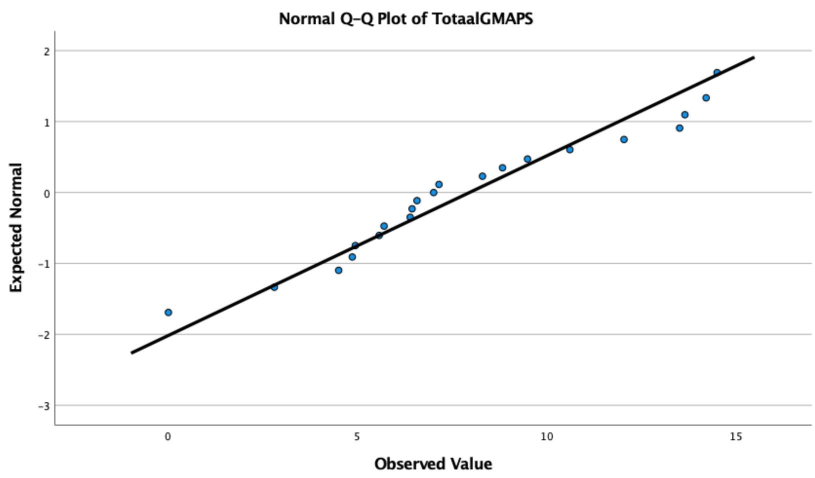

Normal Q-Q Plot of GemDuurAUDIO
Expected Normal
4
3
2
1
0
−1
−0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Observed Value

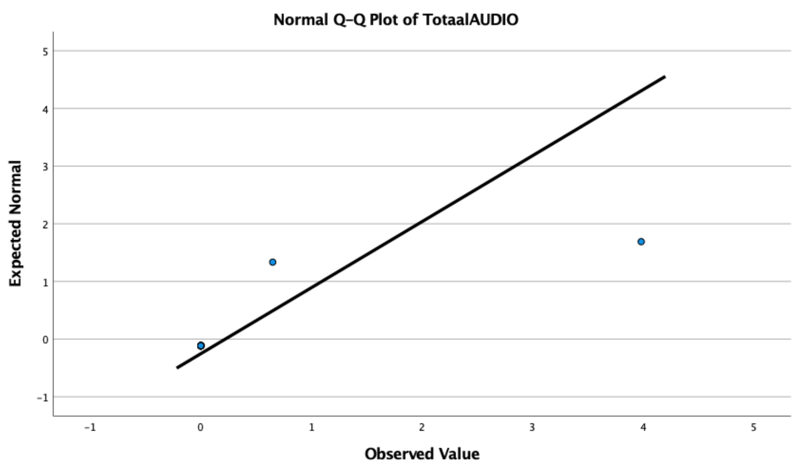

Normal Q-Q Plot of GemDuurBEE
Expected Normal
4
3
2
1
0
−1
−2
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
Observed Value

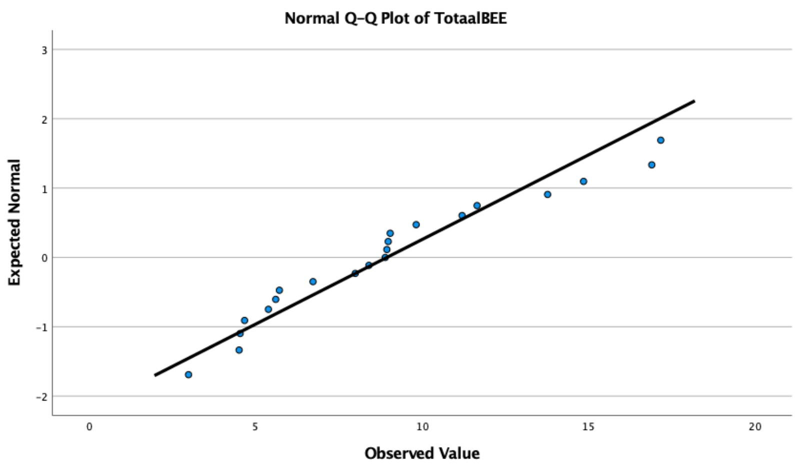

Normal Q-Q Plot of GemDuurBEE
Expected Normal
4
3
2
1
0
−1
−2
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
Observed Value

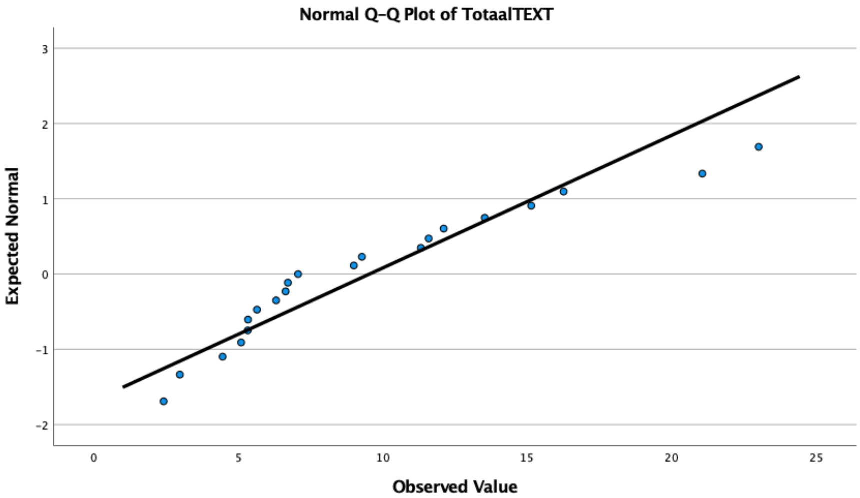
Average total duration

The sphericity assumption was not violated ($\chi^2 = 10.089$; $p = 0.073$).



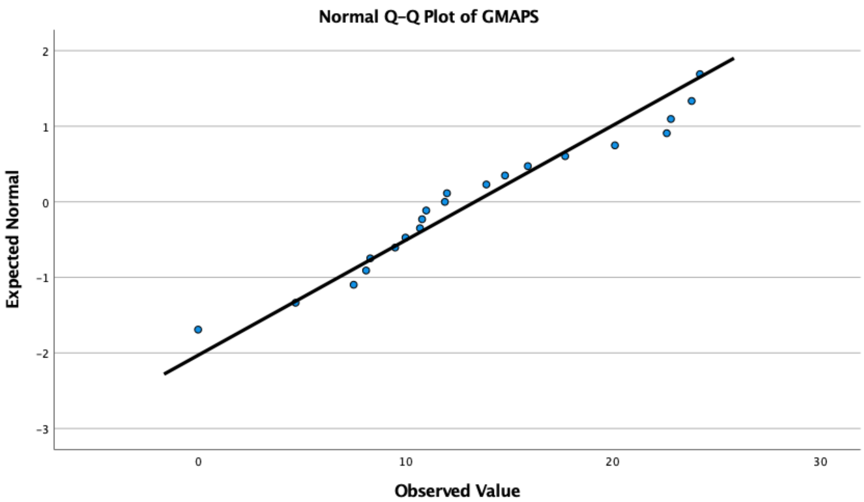


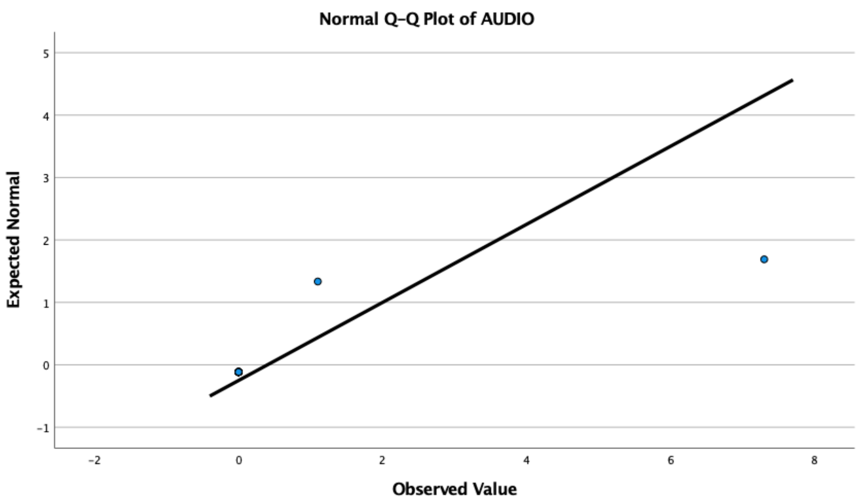


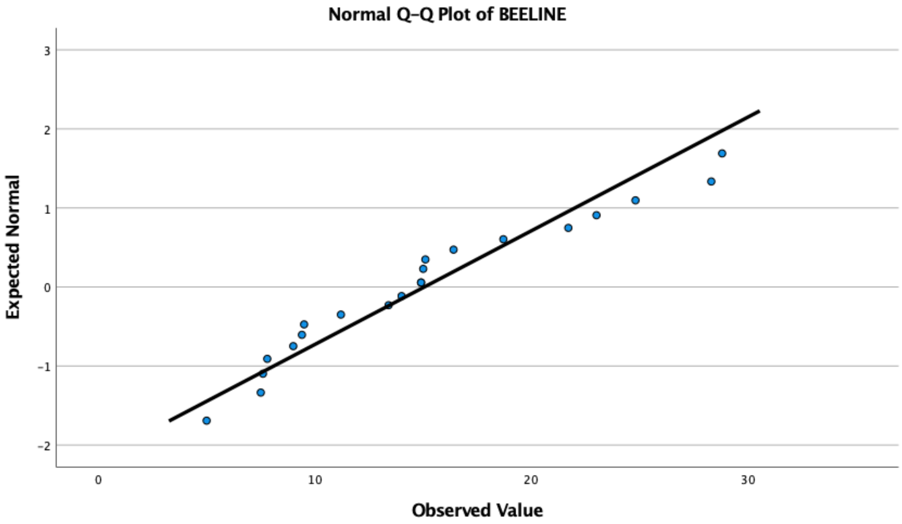


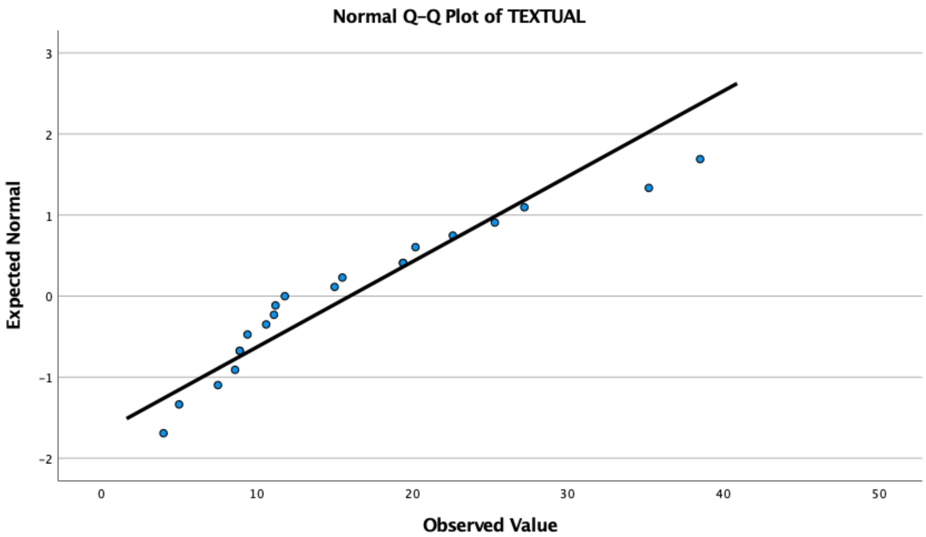
Percentages

The sphericity assumption was not violated ($\chi^2 = 10.354$; $p = 0.066$).






Normal Q–Q Plot of BEELINE
Expected Normal
Observed Value
3
2
1
0
−1
−2
0
10
20
30


Normal Q–Q Plot of TEXTUAL
Expected Normal
Observed Value
3
2
1
0
−1
−2
0
10
20
30
40
50