Performance of Dutch and Non-Dutch Cyclists with Text-free versus Text-based Navigation Devices: User Experience Evaluation

Shiyi Zhang

s3899802

Department of Psychology, University of Groningen

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Group number: PSB3-BT_2122_2a_03

Supervisor: prof. dr. D. (Dick) de Waard

Second evaluator: dr. M.R. (Mark) Nieuwenstein

In collaboration with:

Amir Danial Bin Ridzuan

Lisette Anema

Nele Grabow

Ilse van der Moolen

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Abstract

Objectives: The study aims to evaluate the mental load and usability of the human-machine interaction. Participants used four different navigation devices to propose an optimisation solution for people who could not read the local language and to find their final destinations.

Methods: A Dutch-speaking (*N* = 18) and a non-Dutch-speaking (*N* = 12) group of participants were selected. As-the-crow-flies and turn-by-turn navigation were used in the experiment. Through eye fixations, speed, frustration, subjective mental effort, and preference ratings, the behaviours and usability were measured. In addition, survey results were obtained from the user experience (questionnaire investigation, user feedback), and suggestions for human-machine interaction of navigation tools targeted at non-local language speakers were raised.

Results: Compared to local language speakers (i.e. Dutch), non-local language speakers found it more challenging to find the destinations. A text-free map interface is recommended to support this specific group. The turn-by-turn moving map that includes both symbols and text is the most preferred navigation tool for all; a pure text-based map is the most demanding in terms of mental effort and the least preferred.

Conclusion and Discussion: The study suggests that a text-free map will not only be beneficial for non-local language speakers but also for local language speakers. The turn-by-turn navigation is easier to use, but participants reported more freedom using the as-the-crow-flies navigation.

Keywords: as-the-crow-flies, cycling, eye fixations, field studies, human-computer interaction, local and non-local language speakers, navigation, text-free map, turn-by-turn, user studies, way-finding.

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Maps Play a Significant Role in Traveling

Exploring new places is one of the benefits of travelling. However, way-finding could be difficult due to unfamiliar surroundings, poorly designed signs, and personal reasons (e.g. lack of way-finding skills, language barriers, hearing problems, visual impairment, inability to read signs or text). Nowadays, travellers no longer have to worry about getting lost due to the progression of new navigation technology. Navigation technology, defined as any technological advancement that enables humans to navigate (McPherson, 2009), has a central role in all transporting settings, such as walking, driving, and cycling. Tools (such as paper maps, satellite navigation systems, interrogation navigation, and sign recognition navigation) are commonly used in the way-finding process.

A map is a representation emphasising relationships between objects, areas, themes, or places in some space (National Geographic Society, 2022). Most of the maps contain two main elements, text-based and text-free information.A text-free map is characterised by an interface without any text while using images, signs, and audio (Bao, 2016). The mainstream maps are usually a combination of both graphs and texts. Though a text-based interface is less appreciated than a text-free interface for non-local-language speakers (Medhi & Toyama, 2006), the development and availability of text-free maps lag far behind that of text-based maps (Bao, 2016). There is no advanced text-free maps with new technology to replace the text to cater to illiterates and non-local-language speakers. Designing a text-free map that relies heavily on symbols and signs could help non-local-language speakers (Medhi, 2006). Using more landmark-signs to replace the texts can help deliver the geographic information better (Bao, 2016). Auditory assistance is an alternative way to replace text; one study has proved that audio explanations could assist illiterate people in comprehending a text-free interface more accurately (Medhi & Toyama, 2007). Users with low-reading skills have proven the effectiveness of text-free interfaces (Elmeroth, 2003; Cooter, 2006). Semi-literate users can access the interface by combining text and audio; users can gradually gain the relevant information related to way-finding by listening to the audio.

Cognitive Theories Related to Way-Finding on a Bicycle

Cognitive map design research seeks to understand human cognition to improve the design and use of maps. Users can learn about space by viewing images on maps and acquiring spatial information through maps (Bertin et al., 2011). Way-finding is one of the significant roles maps play in our daily lives (Hallpike et al., 1986; Passini, 1996; Golledge, 1999; Schmid, 2010). According to Huang et al. (2002), way-finding includes interaction between human and physical space. It is the cognitive and corporeal process that determines a path between the origin and destination (Symonds et al., 2017). Spatial navigation, which refers to the ability of an individual to identify the current location in the environment and navigate to another unseen destination (Golledge, 1999). Way-finding is also commonly referred to as spatial navigation,which includes solving physical-spatial problems, sensing and perceiving the environment, translating environmental cues into plans, and implementing them (Niu et al., 2007).

The way-finding process is divided into three parts: spatial cognition, way-finding decision making and execution (Passini, 1992). Spatial ability refers to an individual's ability to make sense of symbolically structured, non-linguistic data based on representations, transformations, generation, and recall (Linn & Petersen, 1985).

With spatial ability, people can translate 2-D images from a map to 3-D images in real life, recognise physical space, make decisions and execute this task, thus realising successful navigation (Lawton, 2010). If we consider the spatial navigation process of getting from a location to a destination accurately and quickly as a task or a problem to be solved, the solution to this problem requires the application of appropriate approaches and strategies. In the navigation process, different spatial information and spatial knowledge are acquired, mastered and utilized to different degrees, resulting in different way-finding strategies. The route strategy relies mainly on landmarks and signage, and the orientation strategy depends primarily to subject orientation and geospatial cues (e.g., the sun's orientation). Spatial navigation is a relatively complex and comprehensive spatial ability that involves a variety of more basic spatial cognitive components, including spatial orientation, spatial visualization, judging spatial relationships, and spatial perception. Tolman et al. (1940) had already proposed the concepts of spatial orientation and spatial navigation when they explored rats' cognitive maps. Self-orientation plays a crucial role in spatial navigation (Sheynikhovich et al., 2009). Guilford et al. (1948) considered spatial orientation as the ability to perceive, judge (e.g., the spatial arrangement of stimuli), and make decisions about the spatial arrangement of stimuli (Lohman, 1996; Ekstrom et al., 2018). Spatial navigation refers to the subject's recognition and understanding of the arrangement of elements within the visual stimulus pattern and the body as a reference for spatial orientation. Route knowledge and orientation knowledge (also known as survey knowledge) are the basis of explaining the way-finding strategy.

The way-finding process relies on the individual's multichannel perceptual processing of environmental and self-motor cues, spatial operations and execution, which involve various spatial representations (Mark et al., 2010). Individual differences exist in this complex process. Route and orientation strategies are two types of way-finding strategies. Humans' memory represents this spatial layout of an individual's everyday physical environment (Gärling et al., 1981). Specifically, individuals recognise and use environmental features and spatial cognitive models. Different individuals recognise and use environmental features and spatial cognitive representations differently (Shelton et al., 2013).

Cognitive anthropology relied on language to access people's ways of thinking. In the 1950s and 1960s, component analyses postulated isomorphic relationships between cognitive categories and word labels. Component analyses sought to discern the logical structure of word place arrangements in representational cultural domains. In the following decades, cognitive anthropology became more nuanced. Nonetheless, we usually infer mental models of interlocutors from linguistic communication. Although linguistic representations are frequently used by human-beings in cognitive anthropology, some types of knowledge are difficult to explain in words (Shore, 1996). Language is associated with spatial representations and behaviours, particularly in relation to landmark use (Hermer-Vasquez et al., 2001, Pyers et al., 2010), but the role of language in human navigation remains unclear. Language is likely to have an impact on navigation either through domain-general processes, or through mechanisms that are specific to the language domain (Anna et al., 2011). Language's role in spatial cognition has not been clearly defined regardless of the mechanism through which it operates, especially in a dual-task situation. Different sources of information about the environment may be emphasized, enhanced, or integrated through language (Haun et al., 2006, Landau and Lakusta, 2009, Spelke and Tsivkin, 2001, Waxman and Markow, 1995). Language may also have multiple effects on representations of the environment, and these possibilities are not mutually exclusive. Recent research has shown that mastery of specific spatial language characteristics is related to performance on different spatial tasks (Pyers et al., 2010). One study has shown that language could play specific roles in children's development of spatial cognition (Anna et al., 2011).

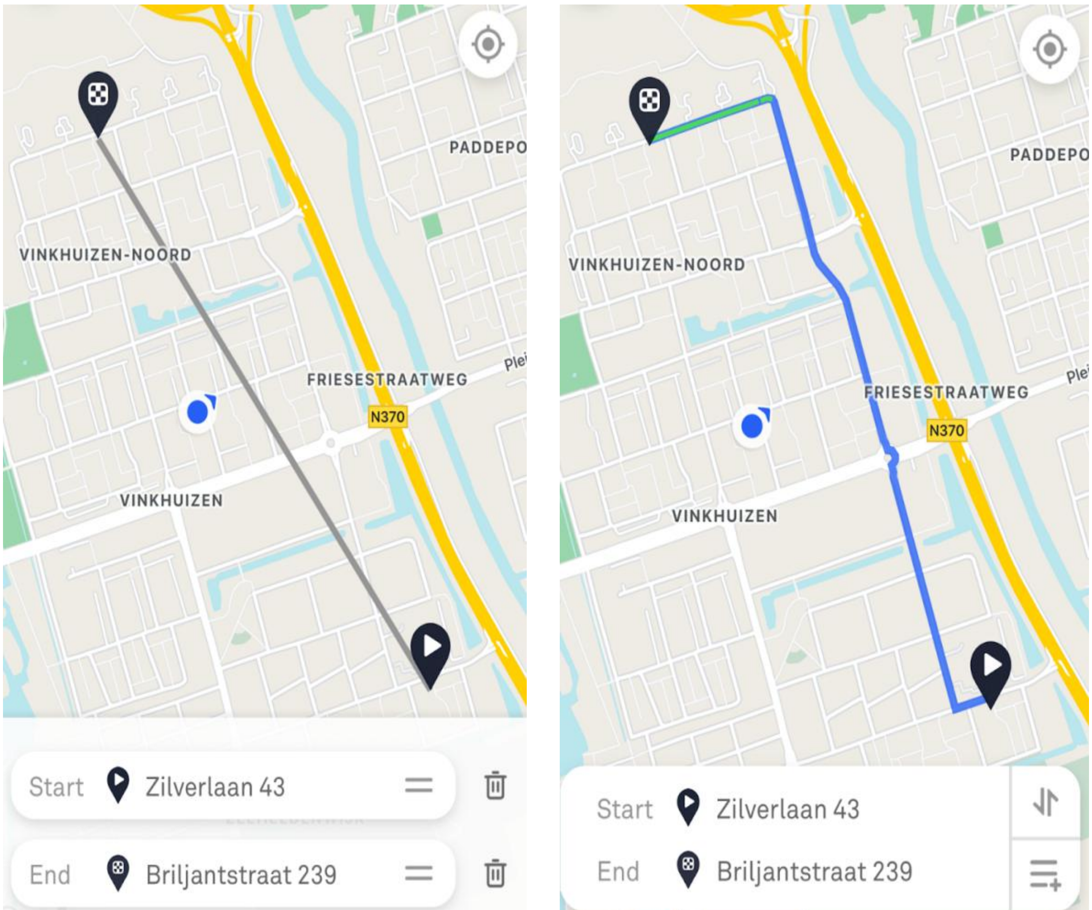
Navigating using a device while travelling by bicycle may be different from doing so while traveling by foot. Same result pattern has also shown in driving a fast-moving vehicle safely, way-finding requires greater mental effort than walking by foot (Ben-Elia, 2021). The use of a navigation devices while cycling can lead to dual-task problems similar to those that occur while using a smartphone to read or write texts while riding (Ahlstrom et al., 2016). It is especially high mental effort demanding to use a smartphone while cycling (De Waard et al., 2014). One possible measure that could reflect the level of navigation demands in cycling is speed. When people are engaged in a dual-task, or even, a multi-task situation, they slowed down to meet the increased demands of a secondary task (De Waard et al., 2010). As a digital communication channel, eye tracking systems have become more and more effective over the years, which helps get users' unconscious performance feedback (Menges et al., 2019).

Using Different Types of Navigation Devices to Disseminate Information

Currently, the most popular navigation systems are based on TBT (turn-by-turn) navigation, which presents instructions at each decision point (Gian-Luca et al., 2020). As-the-crow-flies (ATCF) is a navigation method rooted in developing navigation methods for the blind (Jack et al., 1998). The disparity between ATCF and TBT navigation is that ATCF does not offer direct guiding instructions (Figure 1(a)(b)), nonetheless, ATCF provides a general direction to the destination. As demonstrated in Figure 2 (g) (h), *Beeline* is an mobile navigation application designed for cycling, which has a simple, straightforward, and text-free interface (Beeline, 2022). The interface consists of an arrow in the compass mode, which points to navigation direction and information about the remaining distance and leaves out almost all textual information. By using universal signs (e.g. an arrow), people from various linguistic and cultural backgrounds are also able to adapt to new environments (Lee, 2014).

Figure 1

Mechanisms comparison between TBT and ATCF



(a) (b)

Note. (a) The navigation mechanism behind ATCF. (b) The navigation mechanism behind TBT. Both (a) and (b) show routes from Zilverlaan 43 to Briljanstraat 239.

Study Aims

By measuring speed, eye fixations, frustration, mental effort, and preference, users' performances for graphical (symbol-text-combined Google Maps™), auditory (using only voice Google Maps™), text-free (using only symbols Beeline), and text-based (using plain text) maps will be compared in two language groups. The evaluation results will illustrate which kind of maps would lead to the fastest speed, the least frustration, the lowest mental effort rating to navigate with, and assess different interfaces on user-friendliness perspective.

Non-local-language speakers can read text interfaces with their language; they do not particularly lack of cognitive spatial orientation skills (Alptekin, 1986; Hornberger et al., 1996). In the long term, this study could be helpful in developing a portable system that will enable individuals with reading impairments to navigate familiar and unfamiliar environments without extra external assistance.

The following specific research questions have been posed:

1. Do non-local language speakers more efficiently and effectively use a text-free map (Beeline as-the-crow-flies compass mode) than a text-based map (Printed turn-by-turn textual instructions)?
2. Which kind of text-free map (Beeline ATCF compass mode and Google Maps™ TBT auditory mode) leads to the destination quicker?
3. How effortful is it to cycle with different types of navigation?

Researcher formulated the following hypotheses:

Hypothesis 1. A text-based map leads to reaching the destination slower, especially for non-local-language speakers.

Hypothesis 2. Users evaluate text-free interfaces more positively than text-based interfaces.

Methods

Participants & Apparatus

Thirty participants were recruited via word of mouth and classified into two groups: local language speakers (Dutch) and non-local language speakers (Non-Dutch). Data of three participants was incomplete for various reasons like equipment failure and voluntarily quitting. Eighteen participants were classified as the *local-language-speaker* group because they self-reported that they can speak Dutch fluently, and the other 12 participants were classified as the *non-local-language speaker* group. The sample was of comparable size to that employed in the previous field study (De Waard et al., 2017). All of the participants reported that they can speak English and understand basic instructions in English. Their ages ranged from 19 to 43 years old, but overall this study involved young adults (M = 24.7, SD = 5.7). Furthermore, all of them brought their own bikes and had the ability to cycle alone. Most of them cycle on a regular basis and rely on cycling for transportation. Only two-thirds of them use navigation tools (N = 21), and Google Maps™ is the most frequently used tool. None of them had used the Beeline application or a pure text-based map. The order of map conditions was balanced among participants, but the order of the four routes was the same for all (Appendix B).

Researchers compared four types of navigation support: A moving visual TBT map displayed on a mobile phone (Google Maps™ visual format); An auditory TBT navigation guidance (Google Maps™ auditory output); A symbol-based ATCF navigation guidance (Beeline); A printed textual instruction map.

The textual instructions were printed out on A5 size paper and put in a holder attached to the handlebar (Figure 2(a) (b)). Textual instructions for four routes can be found in Appendix D. Their bicycle was equipped with different devices and a

Contour +2 GPS camera (Figure 2(c)). Google Maps™ and Beeline applications were installed on an *iPhone 7*, which was mounted on the handlebar of the participant's own bike (Figure 2(d)). In the visual TBT map condition, Google Maps™ was used in the default setting, and the auditory information was turned off. Participants received real-time instructions about when and where to take turns depending on location (Figure 2(e)). While in the auditory condition, participants only got auditory turn-by-turn route instructions. By using Bluetooth earbuds, participants got auditory instructions about directions in English but street names in Dutch. In the meanwhile, the phone screen was turned down in the holder, so only auditory instructions were available. Bluetooth earbuds were provided (Figure 2(f)), but participants who were used to cycling with their own earbuds were allowed to use them.

Table 1

Information types and conditions

Condition	Instructions	Turn-by-turn	Preview	Ego position
Visual Google Maps™	Symbols and text combined moving map	Yes, partly	Limited	Yes, visible
Auditory Google Maps™	Auditory instructions	Yes	No	Yes, used
Beeline	Symbol	No, ATCF	No	Yes, visible
Textual Map	Textual instructions	Yes	Yes, full	No

Participants did not program or operate the devices themselves in any of the conditions. All the questionnaires were on paper.

Figure 2

Devices included in the study

Boraxstraat 115 9743 VM Groningen

Head northwest on Boraxstraat toward Pyrietstraat
110 m

Turn **right** onto Pyrietstraat
270 m

Turn **left** onto Diamantlaan
Go through 1 roundabout
700 m

Turn **right** onto Edelsteenlaan
200 m

Turn **right** onto Amethiststraat
91 m

Turn **left** to stay on Amethiststraat

Destination will be on the left
66 m

Amethiststraat 31 9743 KE Groningen

(a) (b)

(c) (d)

(e)

(f)

(g)

(h)

Note. (a) Printed textual instructions set up. (b) Sample textual instructions used from Boraxstraat 115 to Amethiststraat 31 (see detailed textual instructions for four routes in Appendix D). (c) Beeline (d) example of the interface of Google Maps™. (e) Bluetooth Earbuds used in Google Maps™ voice navigation condition. (f) Camera with GPS Tracker. (g) iPhone mounted on the handlebar. (h) example of the interface of Beeline, indicating a general leftwards direction and 111m left.

Study Task Design

The experiment was performed in Vinkhuizen, which is a quiet neighbourhood in Groningen. Rush hours were avoided to ensure participants' performance would not be influenced too much by external factors. The four sections were similar in length (1100m-1700m), on average around 1400m (Appendix C). The The University of Groningen Ethical Committee Psychology had approved the study.

The general study method consists of three main parts: filling in a pre-questionnaire of the whole experiment; cycling four different routes using the randomly assigned four kinds of navigation tools (see Figure 2); filling in a post-questionnaire after the whole experiment. Moreover, during the second part, after each map condition, participants were required to fill in a post-condition questionnaire after each route.

Table 2

Research Methods

	Aim	Apparatus & Data collection methods
Subjective Measures	Demographic information & cycling preference	Pre questionnaire (Appendix A.)
	Subjective Mental Workload	Post condition questionnaire (Appendix B.)
	User experience and preference	Post experiment questionnaire (Appendix C.)
Performances Measures	Calculated average speed	Timer
	GPS speed	Contour +2 GPS camera
	Eye fixations	Contour +2 GPS camera

Subjective Measures

Demographic Information & Cycling Preference.

Researchers asked about the following topics in the pre-questionnaire: demographic data (gender, age), bicycle use generally and in demanding situations, use of navigation systems while cycling, reasons for utilizing these devices, and frequency of use. Three factors were used to quantify the frequency of bicycle use: the amount of time spent cycling each week, the average distance traveled per ride, and the reliance on bicycles for transportation (see detailed pre-questionnaire in Appendix A1). A composite scale listing four usage types measured the use of navigation devices while cycling. For each of these usages, respondents had to indicate how frequently they engaged in that behaviour during a typical cycling week and how familiar they were with their preferred navigational aid. Participants were asked to rate their familiarity with the experiment's location. A Likert scale from 1 (*Not familiar at all*) to 5 (*Extremely familiar*) was used.

Subjective Mental Workload.

Participants were asked to answer questions about the navigation systems every time when they finished a condition (Appendix A2). Those questions were about how much mental effort they invested during the ride using the *Rating Scale Mental Effort, RSME* (Zijlstra, 1993). RSME is a unidimensional scale representing effort required at irregular intervals as a line from 0 to 150. The rating of 2 corresponds to *no effort*, 37 to *some effort*, 85 to *great effort*, and 112 to *extreme effort*, while the scale runs beyond this point up to 150. They were asked to place an X on the scale on the location that corresponds with subjectively invested mental effort.

User Experience and Preference.

After the participants finished cycling all four routes, they were asked to compare their experience with the navigation systems (Appendix A3). They also needed to rate and rank the four navigation ways and indicate which one they would like to use again.

Performances Measures

Speed.

Calculated Speed.

Each participant's time to complete each experiment condition was measured using a stopwatch. The average speed of each participant in each lag of the ride was calculated by the formula: $Sr = d / t$, where d is the estimated distance by Google Maps™ in turn-by-turn mode (see detailed calculation procedure in Appendix B). This speed measure includes wrong turns taken and therefore also reflects how efficient cycling with the device was.

GPS Speed.

Another way to determine speed is using GPS data obtained from the Contour +2 TM camera. GPS files were exported and imported into an Excel spreadsheet using Contour's StoryTeller (version 3.6.2.1043). In order to minimise the influence of external factors (e.g. crossing a road and the presence of other traffic participants), speed was calculated based on a segment of 100m where participants only received one navigation message.

Eye Fixations.

Based on the video recording, the length and quantity of fixations on the device were measured on the same 100 m section. This was carried out manually using the ELAN program (version 4.9.4).

Data Analyses

The statistical analysis was performed using JASP and SPSS. The study concentrated on the variations among language groups and environments. The calculated average speed, GPS speed, eye movement and subjective mental effort questionnaires were used as variables to reflect the participants' cycling performance and mental effort. Repeated measures ANOVA and multiple comparisons Bonferroni adjusted were used to investigate the effects of text-based and non-text-based navigation on the four indicators. Correlations analyses were conducted to link results from different measures.

Results

Study results are summarized in this section, including the analysis of the statistics of the data and the characteristics of human-computer interaction for bicycle navigation.

Researchers are interested in how local-language speakers (i.e. Dutch) would perform compared to non-local-language speakers.

In this case, researchers would have two independent variables:

1. Language, with two levels: Dutch and non-Dutch
2. Navigation tools, with four levels: Google Maps™ Visual TBT Mode (GMV), Google Maps™ Auditory TBT Mode (GMA), Beeline ATCF mode (BL), and Textual TBT Map (Text)

Demographics

The majority of participants (96.7%) cycled more than once each week, and more than 86.6% of them did so four or more times per week. According to the questionnaire result, 93.2% of participants' average cycle length per ride takes more than 10 minutes. No significant difference is found in the frequency in which Dutch and non-Dutch speakers used navigation apps per week. The frequency of non-Dutch speakers who do not use navigation tools is half that of Dutch speakers, with seven Dutch speakers (38.8%) versus two non-Dutch speakers (16.6%). For those who use navigation apps, no one had used the Beeline or Text Instructions before.

Speed

Calculated Speed

The results illustrated that the calculated speed of participants using four navigation devices indicating that the use of different navigation devices had a significant effect on participants' cycling speed at 5% level (Table 4). The study showed that the use of Google Maps™ Visual (Textual Graphic Combined TBT Map) led cyclists to their destinations the most accurately and quickly, regardless of whether the cyclists spoke the local language or not. The use of Textual Map (Plain Text TBT Map) was least beneficial for cyclists to find their destinations quickly (Table 3). Moreover, participants in the "local-language speakers" group cycled significantly faster than participants in the "non-local-language speakers" group, $F(1, 25) = 4.99$, $p = 0.035$ (Table 4 and Table 6). Significant p-values for the repeated measures ANOVA support this suggestion. For both local and non-local language speakers, their average speed rank was: Visual Map > Auditory Map > Beeline > Text Map (Figure 4).

Table 3

Descriptive statistics for the two speed measures in m/s

	Calculated Average Speed (m/s)				GPS Speed (m/s)			
	GMV	GMA	BL	TEXT	GMV	GMA	BL	TEXT
N(Valid)	30	29	29	29	23	24	24	23
N(Missing)	0	1	1	1	7	6	6	7
M	4.356	4.210	3.915	3.655	5.297	5.064	5.049	4.851
Std	0.896	0.818	0.740	0.852	0.927	0.815	0.745	0.662

Note. M, mean; Std, standard deviation; GMV = Visual TBT Google Map; GMA = Auditory TBT Google Map; BL = Text-free ATCF Beeline; TEXT = Printed TBT textual map. Calculated speed is over the complete 1.1-1.7 km section, GPS speed is on a selected 100 meter track (See detailed descriptive statistics for GPS speed in Table 7).

Table 4

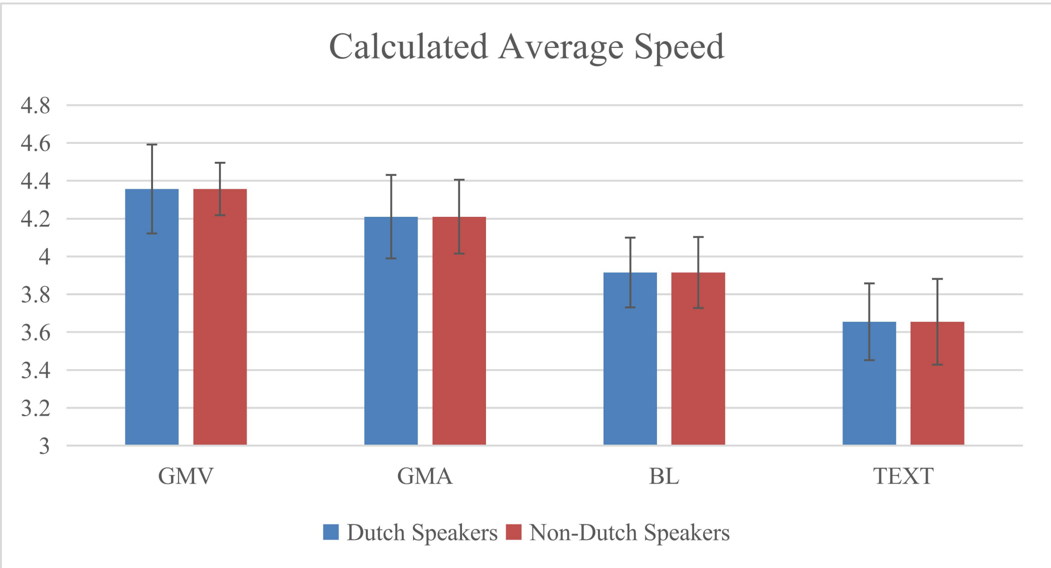
Repeated measures ANOVA on calculated speed

Source	SS	df	MS	F	p-value
Between-Subjects Effect					
Language	5.327	1	5.327	4.994	0.035*
Residuals	26.668	25	1.067		
Within-subjects Effect					
Navigation Tools	7.758	3	2.586	5.147	0.003**
Navigation Tools * Language	1.815	3	0.605	1.204	0.314
Residuals	37.680	75	0.502		

Note. *p < 0.05; **p < 0.01. SS, sum of squares; df, degrees of freedom; MS, mean squares; F, F statistics.

Figure 3

Calculated average speed per condition in m/s



Notes. N = 27. GMV = Visual TBT Google Map; GMA = Auditory TBT Google Map; BL = Text-free ATCF Beeline; TEXT = Printed TBT textual map.

Table 5

Post hoc tests on calculated average speed

		Mean difference (95% CI)	Cohen's d (95% CI)	Pb	Pholm
GMV	GMA	-0.008 (-0.549, 0.533)	-0. 010 (-0.682, 0.662)	1	0.968
	BL	0.371 (-0.170, 0.913)	0.463 (-0.232, 1.158)	0.401	0.245
	TEXT	0.655 (0.114, 1.197)	0.817 (0.076,1.558)	0.009**	0.008**
GMA	BL	0.379 (-0.162, 0.921)	0.473 (-0.223, 1.169)	0.368	0.245
	TEXT	0.663 (0.122, 1.205)	0.827 (0.085, 1.569)	0.008**	0.008**
BL	TEXT	0.284 (-0.257, 0.825)	0.354 (-0.331,1.039)	0.956	0.319

Note. GMV = Visual TBT Google Map; GMA = Auditory TBT Google Map; BL = Text-free ATCF Beeline; TEXT = Printed TBT textual map; 95% CI, 95% confident intervals.

*Note.*P-value and confidence intervals for contrasting estimates from a family of 6 adjusted for (confidence intervals corrected using the Bonferroni method).

Note. Results are averaged over the levels of: Language.

Note. *p < 0.05;**p<0.01. In all conditions, standard error = 0.200.

Table 6

Post-hoc comparison between two language groups

		Mean difference (95% CI)	SE	t	Cohen's d (95%CI)	Pb	Pholm
Non-Dutch	Dutch	-0.460 (-0.884, -0.036)	0.206	-2.235	-0.573 (-1.127, -0.019)	0.035*	0.035*

Note. Results are are an average over the following levels: Navigation Tools.

GPS Speed

Same statistical methods were used to analyse the GPS speed on the selected 100-meter track. A repeated measures ANOVA was performed to compare the effect of using different navigation tools on speeds. For each condition, there were some data missing (Table 4 and Table 7), which could be a possible explanation for higher p-values. Speeds on the selected representative 100-meter track where other traffic did not hamper the speed and road instructions about upcoming turns were given differed on 10% level between the four navigation conditions, with $F(1, 57) = 4.16$, $p = 0.06$. Meanwhile, the difference in speed between language groups also revealed a statistical significant result on 10% level, with $F(1,19) = 4.16$, $p = 0.56$. Different speed trend was spotted using GPS speed. For non-local language speakers, their average speed rank was: Visual Map < Auditory Map < Beeline < Text Map (Figure 4).

Table 7

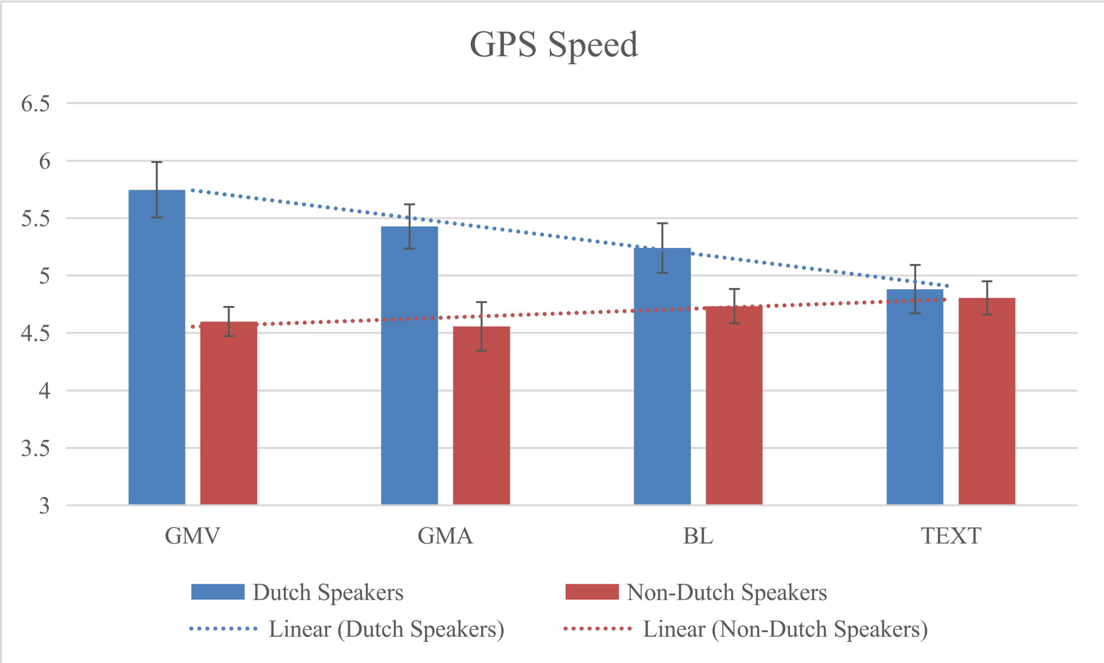
Descriptive statistics for GPS speed in m/s

		Valid	Missing	Mean	Std. Deviation	Minimum	Maximum
GMV	Non-Dutch	9	3	4.600	0.383	4.005	5.157
	Dutch	14	4	5.746	0.901	4.480	7.742
GMA	Non-Dutch	10	2	4.556	0.674	3.474	5.392
	Dutch	14	4	5.427	0.721	4.333	6.802
BL	Non-Dutch	9	3	4.733	0.446	4.059	5.574
	Dutch	15	3	5.239	0.834	3.574	7.018
TEXT	Non-Dutch	9	3	4.805	0.438	4.213	5.569
	Dutch	14	4	4.881	0.788	3.695	6.508

Note. GMV = Visual TBT Google Map; GMA = Auditory TBT Google Map; BL = Text-free ATCF Beeline; TEXT = Printed TBT textual map. Non-Dutch = Non-local language speakers; Dutch = local language speakers.

Figure 4

GPS-based speed per condition in m/s



Note. Error bars reflect standard Error. Linear reflects trending lines.

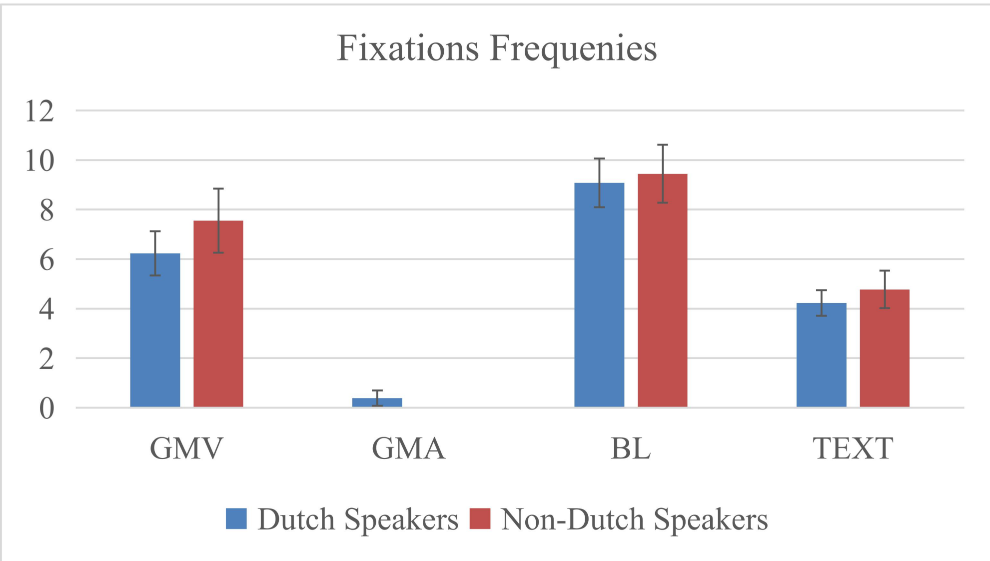
Note. GMV = Visual TBT Google Map; GMA = Auditory TBT Google Map; BL = Text-free ATCF Beeline; TEXT = Printed TBT textual map.

Eye Fixations

Eye fixations at the device were measured and graded using video recordings of the chosen 100 m tracks. The mean number of fixations was not statistically different in either language group at the 5% level ($F(1,19) = 0.089$, $p = 0.768$, Figure 5). Between the four circumstances, differences in the mean number of fixations were discovered ($F(1.942,36.906) = 70.062$, p 0.001). Post hoc p tests showed that all conditions had significantly different frequencies (p 0.05), with the exception of the visual Visual TBT Google Map and Text-free ATCF Beeline conditions. Participants paid substantially greater attention to the Google Maps™ visual directions and the beeline than to the text-based instructions. Additionally, the amount of time spent staring at the device and the average length of fixations were examined. Figure 6 depicts the typical amount of time spent each fixation. $F(1,22)=1.53$, NS, $\eta^2 = 0.065$, again no differences between the language groups were discovered. Excepting Visual TBT Google Map and Text-free ATCF Beeline condition, all the other conditions differed significantly from each other ($p < 0.05$). The participants took longer looks at the textual instructions, but shorter looks at the beeline and google maps visual condition. The paper map condition had the longest average fixation time. (Figure 6).The amount of time, as percentage of the total cycling time, the participants fixated on the navigational devices did not differ much (Figure 8).

Figure 5

Frequencies of eye fixations at the device

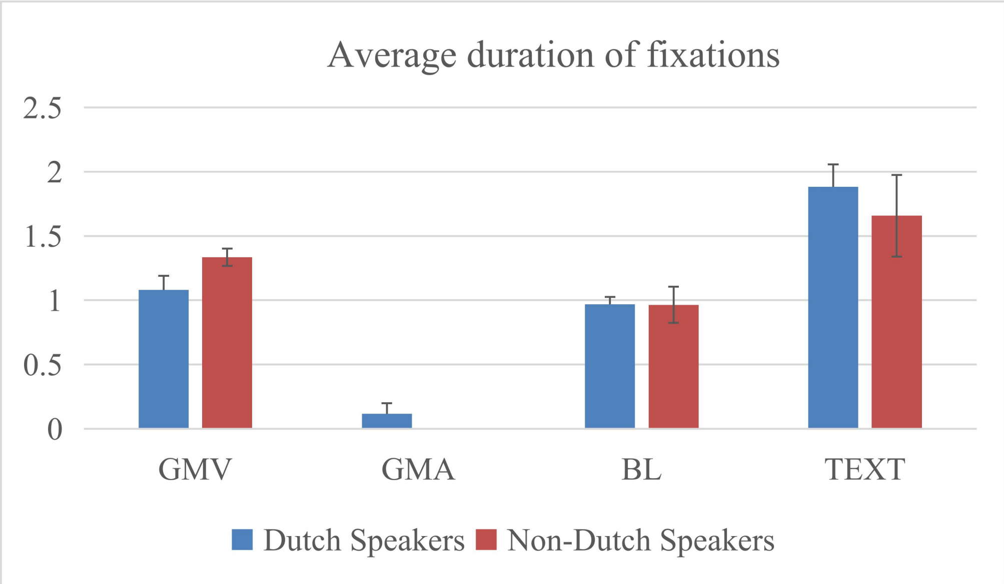


Note. Error bars reflect standard Error.

Note. GMV = Visual TBT Google Map; GMA = Auditory TBT Google Map; BL = Text-free ATCF Beeline; TEXT = Printed TBT textual map.

Figure 6

Average duration of fixations in seconds per condition

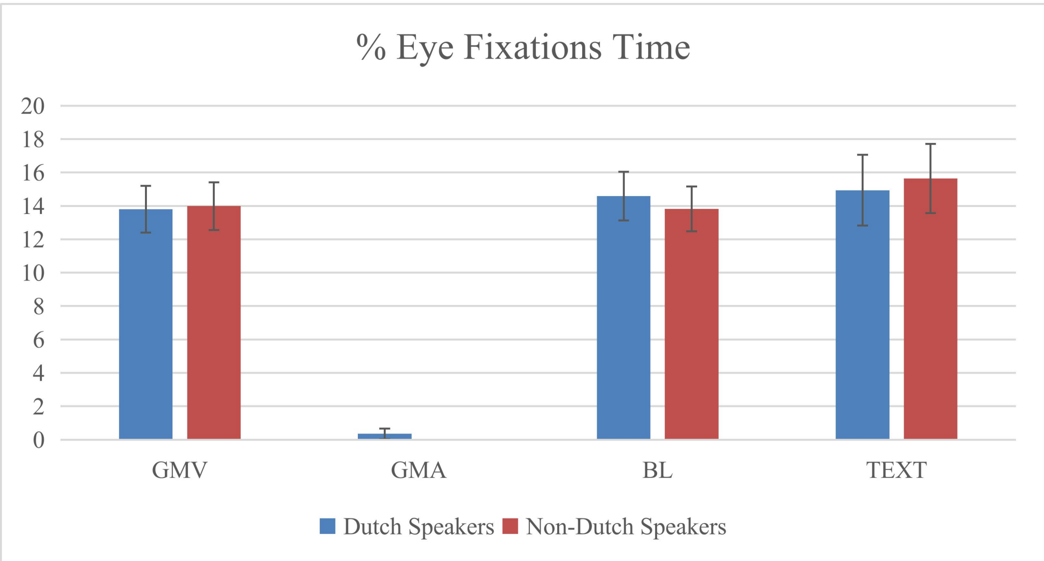


Note. Error bars reflect standard Error.

Note. GMV = Visual TBT Google Map; GMA = Auditory TBT Google Map; BL = Text-free ATCF Beeline; TEXT = Printed TBT textual map.

Figure 7

%-wise Eye Fixations Time



Note. Error bars reflect standard Error.

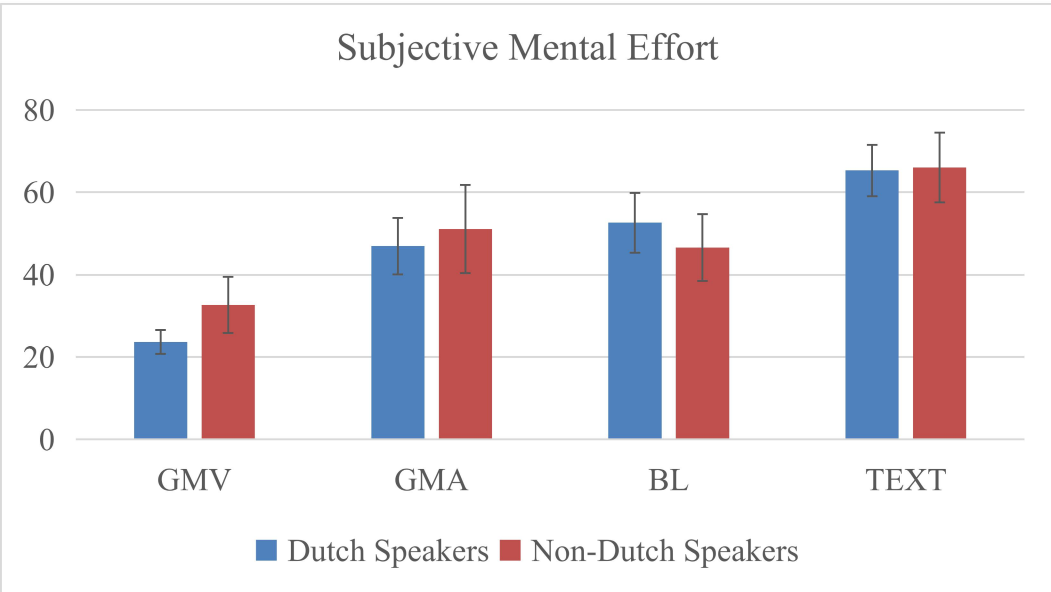
Note. GMV = Visual TBT Google Map; GMA = Auditory TBT Google Map; BL = Text-free ATCF Beeline; TEXT = Printed TBT textual map.

Subjective Mental Effort

The main effect of subjective mental effort was significant (F = 11.778, p < 0.001).,Self-reported mental effort increased followed the order: visual TBT map < auditory TBT map < Beeline ATCF < textual TBT map (Figure 8). Multiple comparisons revealed that the differences between the two levels of navigation tools were significant ($p < 0.05$), except for the mental effort between two text-free navigation tools: Beeline and printed text instruction. There was no evidence that there is a difference between the ratings of the two language groups ($F(1, 27) = 0.092$, $p = 0.764$).

Figure 8

Subjective Mental Effort per condition



Note. Error bars reflect standard Error. GMV = Visual TBT Google Map; GMA = Auditory TBT Google Map; BL = Text-free ATCF Beeline; TEXT = Printed TBT textual map.

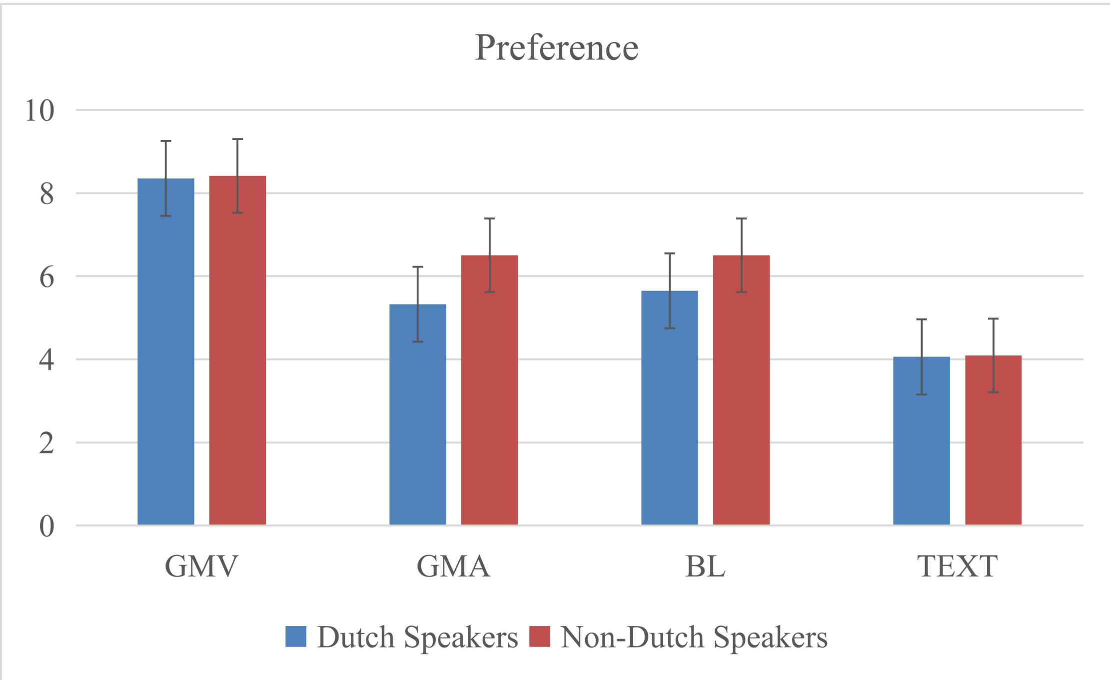
Note. The RSME scale, which ranges from 0 to 150, represents the effort needed at irregular intervals in a single dimension. The scale goes from 2 to 150, with 2 denoting "no effort," 37 denoting "some effort," 85 denoting "great effort," and 112 denoting "severe effort."

Preference

According to the post questionnaire, the text version is least preferred as navigation tool in both language groups (Figure 9). For the preferences we found that Google Maps™ visual is rated significantly higher than the other navigational devices. This also reveals people to have a preference for the textual and symbol combined navigational device. Between the two language groups, there is no statistically significant difference.

Figure 9

Users' post preference bar chart



Note. Error bars reflect standard Error. GMV = Visual TBT Google Map; GMA = Auditory TBT Google Map; BL = Text-free ATCF Beeline; TEXT = Printed TBT textual map. On a scale from 0 -10, 0 means the least preferred and 10 means the most.

Correlations

Calculated cycling speed was correlated with GPS speed, subjective mental effort, frustration, and users' preference (Table 6). The variable calculated average speed and mental effort were found to be strongly negatively correlated in Auditory TBT Map and Textual TBT Paper Map. Same correlation patterns were found between calculated average speed and frustration. Overall, calculated average speed and GPS speed were strong positively correlated in Visual TBT Map condition, Auditory TBT Map condition, and Beeline condition. No relation was found between calculated average speed condition and GPS speed in textual TBT map.

Table 6

Correlations of calculated cycling speed with: mental effort, preference, eye fixations, and GPS speed

	GMV	GMA	BL	TEXT
Mental Effort	0.017 (p = 0.930)	-0.482 (p = 0.008***)	-0.185 (p = 0.338)	-0.503 (p = 0.005***)
Average duration of fixations	-0.379 (p = 0.075*)	-0.223 (p = 0.306)	-0.241 (p = 0.280)	0.215 (p = 0.336)
Eye Fixations Frequencies	-0.051 (p = 0.816)	-0.084 (p = 0.702)	-0.405 (p = 0.061*)	0.006 (p = 0.981)
Preference	0.099 (p = 0.609)	0.227 (p = 0.246)	0.107 (p = 0.587)	0.325 (p = 0.091*)
GPS Speed	0.588 (p = 0.003**)	0.430 (p = 0.041**)	0.453 (p = 0.03**)	0.304 (p = 0.169)

Note. GMV = Visual TBT Google Map; GMA = Auditory TBT Google Map; BL = Text-free ATCF Beeline; TEXT = Printed TBT textual map. *p < 0.1; **p < 0.05.

Discussion

This chapter discusses the findings related to the research gap and the initial research questions. The results of the study are used to summarise the characteristics of the human-computer interaction in bicycle navigation. Differences in the use of navigation devices by local and non-local language speakers, subjective mental effort, and user experience feedback are discussed in this section.

1. It took less time for local language speakers (i.e. Dutch) to cycle to the destination.

2. Both local and non-local language speakers found visual turn-by-turn moving maps the most efficient and effective, with the fastest speed, lowest mental effort, and the lowest eye fixations frequency. The textual-based paper map is the least preferred, which is in accord with the first hypothesis. The two language groups did not significantly differ in their assessments of various navigation aids. For non-local language speakers, the symbol based text-free Beeline demanded less mental effort compared to auditory based Google Maps™. However, the result is in an opposite pattern in the local language group.

Possible Suggestions

Language

This study examined the difference between two language groups and the influence of language on navigating. All of the participants self reported that they can speak English, but only five of 30 participants were native English speakers. English is marked as a second language for both Dutch and other non-native English speakers, which balanced the insufficient language settings. For local language speakers (Dutch), they received instructions in English (second language) and street names in Dutch (local language); for non-local language speakers, they received instructions in

English (second language) and street names in Dutch (non-local language). In all conditions, only street names were in Dutch, the other instructions were in English. One possible explanation for the differences in speed is, Dutch speakers are more familiar with Dutch street names, traffic rules, street views compared to non-Dutch speakers. A clear result shared by both language group is that textual-based map took more mental effort, which is possibly related to how humans encoding symbols and texts information. In this study, due to that fact that Dutch is linguistically close to English, the language influence could be underestimate. One possible suggestion for more specific future studies is conducting the field study in countries where people using languages not being part of the West Germanic family to rule out this factor. Or, choosing two languages that are not belong to the same language family.

Demographics

Another possible explanation for the significantly different speeds is that Dutch participants cycled faster, and non-Dutch participants simply cycled slower. Cycling is a common commuting way in the Netherlands. Most of them would instead cycle than drive when it comes to a short trip (. In Europe, the Netherlands and Denmark are two countries with high travelling distances by bicycle and a low fatality rate (Wegman et al., 2010). Public construction might matter, but the long cycling tradition could also contribute to their faster cycling speed.

Moreover, by analysing the data, researcher found there were only two (11.1%) female participants but 16 (88.9%) male participants in Dutch participants group. However, there were six (58.3%) female participants in non-Dutch participants group. Researchers discovered that men completed races faster and had higher power outputs than women in one study comparing male and female road cyclists in stage races. (Lim et al., 2011). Combined both two points above, researchers should have included a control section without any navigation system, which could be a suggestion for future research.

Spatial Ability

Another uncontrolled factor is participants' spatial ability. As introduced above, spatial ability refers to an individual's ability to make sense of symbolically structured, non-linguistic data based on representations, transformations, generation, and recall (Linn & Petersen, 1985). Early researchers believed that spatial orientation and spatial visualization are two critical components of spatial ability (McGee, 1979). Three additional spatial categories were noted by Linn and Peterson (1985) and included spatial perceptions, spatial visualization, and mental rotation. The common measurement paradigms for spatial perception are the Rod and Frame Test, the Water Level Test, and the Embedded Figures Test. Spatial perception is the capacity to perceive spatial relationships between various objects, including the ability to strip and separate perceived spatial information. The Minnesota Paper Form Board and Paper Folding Test is a popular assessment tool for measuring spatial vision, which is the capacity to handle complicated spatial information in a number of stages. Mental rotation involves the ability to rotate visual stimuli in the mind, and a commonly used test is the Mental Rotation Test. Carpenter and Just (1986) identified a two-factor model of spatial ability: spatial orientation and spatial manipulation. Spatial anxiety and spatial confidence could also be two significant components. Due to time and effort allocation, this study did not test participants' spatial abilities using the possible tests. Participants initial spatial ability could be different between two groups. Future research can investigate this problem by adding a spatial ability test. Possible tests are mentioned above.

User Experience

Nowadays, eye tracking is a common measure to collect user experience data. Fixation is the interval between saccades in which the target is almost stationary (Land, 2003). Humans can capture and collect information by fixation (Land & Lee, 1994). In this experiment, participants captured navigation information when they were cycling. Results show that participants' %-eye fixations have no significant difference between the four conditions. By contrast, researchers spotted opposite significant differences in both frequencies and duration. The findings lead to an interesting question: what is riskier when people are included in a dual-task situation? In this experiment, participants had longer but less frequent fixations in the textual paper map condition, while they had many brief fixations in Google Maps visual and Beeline condition. The results balanced and eventually led to the same non-significant percentage of the time. In one German study, researchers found the more complex the task is, the longer the eye would remain fixated on the object (Klostermann & Moeinirad, 2019), which is consistent with the subjective mental effort results in this study. Here we found higher mental effort and longest eye fixations in the textual paper map condition. But will a difficult dual-task result in more risky behaviours? The answer is still unclear. One study suggested that dual-task difficulty might demonstrate a reduction in the activity of the primary motor cortex inhibition. However, by using functional near-infrared spectroscopy (fNIRS) and transcranial magnetic stimulation (TMS) in a bike-riding study, there was no significant difference spotted in primary motor cortex inhibition between easy and difficult dual tasks (Corp et al., 2018). The mental processes involved in a sequence of fixations are complex and cannot be simply deduced from oculomotor parameters (Schütz, Braun &

Gegenfurtner, 2011). Future studies could focus on the relationship between eye fixations and risky degrees.

In the auditory condition, the screen was turned upside down, and most participants did not look down to the phone. This condition is standardized, with all the participants wearing blue tooth earbuds. In the final evaluation phase, the participants left the most comments about the auditory condition.

Two participants said auditory does not function fundamentally when it tells to them go Left at 600 m when they are on a bicycle. The 600m left is a bit long without a second confirmation. The technology of auditory Google Maps™ also affected users' experience. Two participants reported that the auditory Google Maps™ did not work well at times; they could not hear parts of the instructions, leading to a lower user experience preference score. One participant reported that auditory sometimes would provide instructions too quickly, causing a wrong turn. Four Dutch participants reported that the pronunciation of those Dutch streets is weird. One international participant reported it would be better if they could switch the instructions (not street names) in their native language, i.e. "Turn right in 600m" in Chinese.

To build and design a more user-centered auditory navigation aid, these suggestions could be taken into account:

1. Add double check instructions if it is a long going straight route;

2. Add foreign language auditory options.

For all the participants, this was their first time using as-the-crow-flies navigation tool. Freedom is the most significant advantage that stood Beeline up. Three participants commented that they felt they could control the way they were going and not be controlled by the app. All participants agreed that turn-by-turn navigation tools were easier to use, but they were never stressed about missing turns when using Beeline. One disadvantage mentioned by Beeline is that it is easier to take a turn into a dead end. Another concern of Beeline is related to route; if the route with Beeline is obvious, for example, a straight way without many turns), it would be easier to use. Otherwise, the Beeline could be harder to use.

Other Considerations

A full preview of the printed text map was found to be beneficial. However, in this condition, participants were not able to receive auto-correction instructions if they made mistakes. They were notified by the following experimenter. Also, in the Beeline condition, because there is no "correct answer" to the destination, people will sometimes feel insecure about if they are on the "right" track.

Conclusion

Human-computer interaction is marked as an essential dominant in the navigation field. The paper examines the impact of language on bicycle navigation and explores the results of a bicycle human-machine interface interaction evaluation. Textual-based TBT map is the least popular condition, with the most mental effort input, highest frustration and slowest cycling speed. Text and symbols combined map is the most preferable for both Dutch and non-Dutch cyclists. New navigation tools in the future can refer to these results to improve the user experience for people who cannot understand the local language.

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Appendix

Appendix A1. Pre Questionnaire

Date: Participant number:_______

Pre-questionnaire: A 2 minutes survey

Thank you for taking the time to fill in this questionnaire; it should only take 2 minutes. Your answers will be treated with complete confidentiality, and unless you choose to provide an e-mail address, will be entirely anonymous.

Please fill in the blanks or place an X or checkmark next to the word or phrase that best matches your response.

1. Please indicate your age: ___________
2. Please indicate your nationality: ____________________________
3. Which languages are you capable of speaking fluently? (you can select more than one)
   - ☐ Dutch
   - ☐ English
   - ☐ _____________________
4. What gender do you identify as?
   - ☐ Male
   - ☐ Female
   - ☐ ____________
   - ☐ Prefer not to answer.
5. How many times per week on average do you ride a bike?
   - ☐ None (I do not ride)
   - ☐ Less than one (1 to 3 times per month)
   - ☐ 1
   - ☐ 2 to 3
   - ☐ 4 or more

6. How long do you cycle per ride on average?
   - ☐ Less than 5 minutes
   - ☐ Around 10 minutes
   - ☐ Around 15 minutes
   - ☐ More than 20 minutes
7. How much do you rely on cycling for transportation?
   - ☐ Cycling is my least used form of transportation
   - ☐ I sometimes rely on cycling for transportation
   - ☐ I often rely on cycling for transportation
   - ☐ Cycling is my most used form of transportation
8. Do you use any navigation apps?
   - ☐ Yes
   - ☐ No
9. If you use navigation apps, which navigational aids do you usually use while cycling?
   - ☐ Google Maps
   - ☐ Google Maps voice mode
   - ☐ Beeline
   - ☐ Text instructions
   - ☐ Others: ______________________________________
10. How many times per week do you use your preferred navigational aid?
    - ☐ Less than once a week (I can remember my usual routes)
    - ☐ 1
    - ☐ 2 to 3
    - ☐ 4 or more

11. How familiar are you with your preferred navigational aid?

- ☐ Not familiar at all
- ☐ Slightly familiar
- ☐ Moderately familiar
- ☐ Very familiar
- ☐ Extremely familiar

12. How comfortable do you feel while using your preferred navigational aid?

- ☐ Not comfortable at all
- ☐ Slightly comfortable
- ☐ Moderately comfortable
- ☐ Very comfortable
- ☐ Extremely comfortable

13. How comfortable do you feel as a cyclist?

- ☐ Not comfortable at all
- ☐ Slightly comfortable
- ☐ Moderately comfortable
- ☐ Very comfortable
- ☐ Extremely comfortable

14. How confident do you feel as a cyclist?

- ☐ Not confident at all
- ☐ Slightly confident
- ☐ Moderately confident
- ☐ Very confident
- ☐ Extremely confident

15. How bicycle-friendly was the city that you grew up in?

- ☐ Not bicycle-friendly at all
- ☐ Slightly bicycle-friendly
- ☐ Moderately bicycle-friendly
- ☐ Very bicycle-friendly
- ☐ Extremely bicycle-friendly

16. How familiar are you with Vinkhuizen?

- ☐ Not familiar at all
- ☐ Slightly familiar
- ☐ Moderately familiar
- ☐ Very familiar
- ☐ Extremely familiar

Appendix A2. Post-condition Questionnaire

Date: Participant number:_______

Which navigation is used in this part?______________________________

Questionnaire after each cycling part

You have cycled a part of our route with a certain way of navigation. We now have a few questions for you. Please refrain from discussing your answers with the researcher present. Your answers will be treated with complete confidentiality.

Please circle the number that best describes your choice.

Please rate how comfortable you felt using the navigational aid in this cycling part:

Not sure	1	2	3	4	5	Very sure

Please rate how much you trusted the instructions during this cycling part:

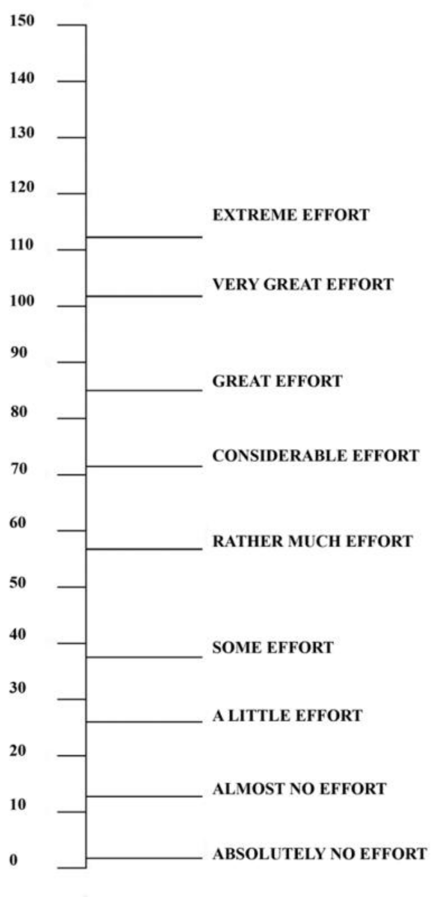
I did not trust them	1	2	3	4	5	I fully trusted them

Please rate how likely you are to use the navigational aid from this cycling part in the future:

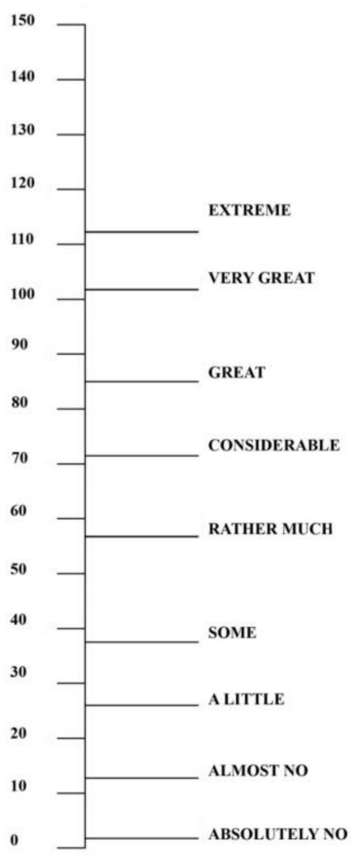
Very unlikely	1	2	3	4	5	Very likely

How much mental effort did navigating this way cost? Please place an X on the scale that you think applies to this navigation device. Do the same for the scale of frustration.

Mental Effort:



Frustration:



Appendix A3. Post-experiment Questionnaire

Date: Participant number:_______

Questionnaire after whole experiment

You have now finished cycling our route. You answered questions about the navigation systems individually and we now ask you to compare the navigation systems.

Please rank the different ways of navigation with a grade from 1 to 10 (1 being the lowest, 10 the highest)

_______ Google Maps (visual instructions)
_______ Google Maps Auditory instructions
_______ Beeline (Compass navigation)
_______ Printed Text instructions

Which of the navigation systems would you use again? (You can select multiple answers)

- ☐ Google Maps (visual instructions)
- ☐ Google Maps auditory instructions
- ☐ Beeline (Compass navigation)
- ☐ Printed text instructions

'As-The-Crow-Flies' navigation provides the most direct path to the destination without giving information about where to turn exactly. This was used in the Beeline device.
Did you have any experience with 'As-The-Crow-Flies' navigation (like the Beeline device) before today?

- ☐ No, none
- ☐ Yes, a little bit
- ☐ Yes, a lot

During the experiment, did you prefer 'Turn-By-Turn' navigation or 'As-The-Crow-Flies' navigation?

- ☐ Turn-By-Turn
- ☐ As-The-Crow-Flies
- ☐ I liked both equally
- ☐ I disliked both equally

If you have any comments or concerns about the experiment, please state them here:

____
____
____
____
____

Appendix B. Speed Calculation

Sr (formerly ToCr) in meters per second

Sr, speed per route segment, relative to the estimated distance of the route segment

SrA =Relative speed on the first route segment

SrB =Relative speed on the second route segment

SrC =Relative speed on the third route segment

SrD =Relative speed on the fourth route segment

$$Sr = d / t$$

Sr=d/t

Sr=m/sec

Estimated route lengths (d)

A (dA) 1700m

B (dB) 1600m

C (dC) 1400m

D (dD) 1100m

Time of completion in seconds

tA =ToC first route segment

tB =ToC second route segment

tC =ToC third route segment

tD =ToC fourth route segment

Sr sorted by condition

SrGMA =Sr of Google Maps™ auditory condition (condition A)

SrGMV =Sr of Google Maps™ visual condition (condition B)

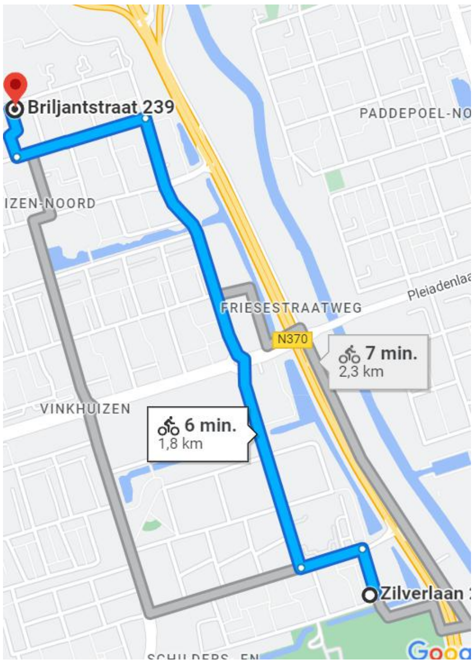
SrBL =Sr of Beeline condition (condition C)

SrText =Sr of textual instructions condition (condition D)

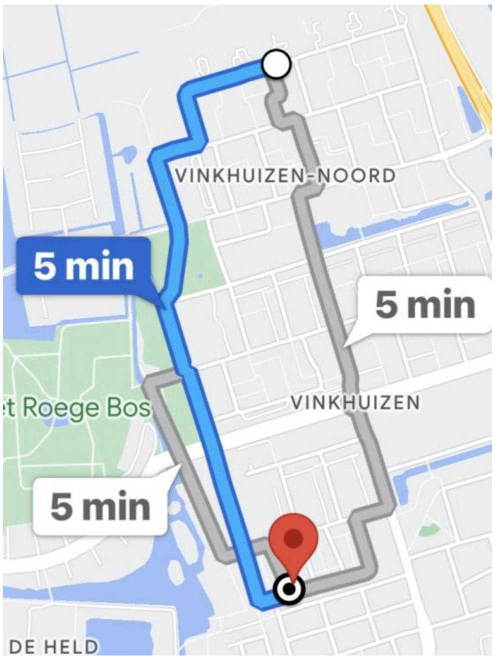
Appendix C. Experiment Routes

Figure 5.

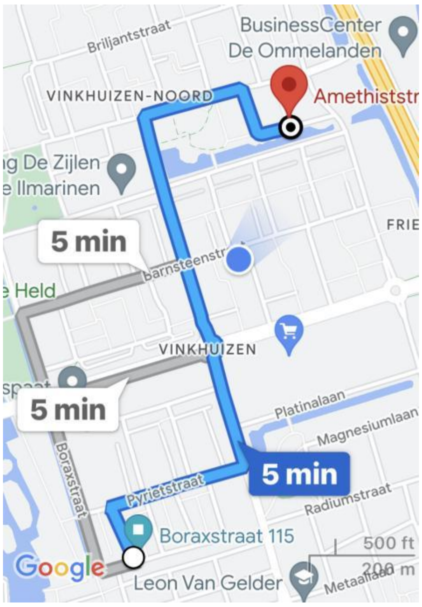
Four routes in the experiment.



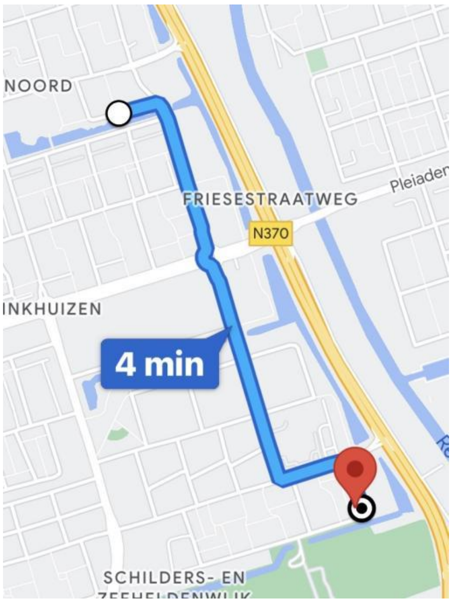
(a)



(b)



(c)



(d)

Note. (a) route A: from Zilverlaan 43 to Briljanstraat 239; (b) route B: from Briljanstraat 239 to Boraxstraat 115; (c) from Boraxstraat 115 to Amethiststraat 31; (d) and from Amethiststraat 31to Zilverlaan 43.

Appendix D. Textual Instructions

Zilverlaan 43 9743 RD Groningen

Head north on Zilverlaan toward Metaallaan
110 m

Turn **left** onto Metaallaan 150m
150 m

Turn **right** onto Goudlaan
Go through 1 roundabout
1.3 km

Turn **left** onto Aquamarijnstraat
290 m

Destination will be on the left
290 m

Briljantstraat 239 9743 NJ Groningen

(a)

Head west on Aquamarijnstraat toward Briljantstraat 11m
Turn **left** onto Briljantstraat
52m

Slight right to stay on Briljantstraat
88m

Turn **left** to stay on Briljantstraat
37m

Turn **right** onto Turkooisstraat
160m

Turn **right** onto Edelsteenlaan
44m

Turn **left** onto Diamantlaan
400m

Keep **right** to stay on Diamantlaan ***Go through 1 roundabout***
300m

Turn **right** onto Pyrietstraat
78m

Turn **left** onto Boraxstraat 290m

(b)

Boraxstraat 115 9743 VM Groningen

Head northwest on Boraxstraat toward Pyrietstraat
110 m

Turn **right** onto Pyrietstraat
270 m

Turn **left** onto Diamantlaan
Go through 1 roundabout
700 m

Turn **right** onto Edelsteenlaan
200 m

Turn **right** onto Amethiststraat
91 m

Turn **left** to stay on Amethiststraat

Destination will be on the left
66 m

Amethiststraat 31 9743 KE Groningen

(c)

Amethiststraat 31 9743 KE Groningen

Head east on Amethiststraat toward Goudlaan
88 m

Turn **right** onto Goudlaan

Go through 1 roundabout
900 m

Turn **left** onto Metaallaan
81 m

Turn **right**

Destination will be on the right
26 m

Zilverlaan 43 9743 RD Groningen

(d)

Note. (a) route A: from Zilverlaan 43 to Briljanstraat 239; (b) route B: from Briljanstraat 239 to Boraxstraat 115; (c) from Boraxstraat 115 to Amethiststraat 31; (d) and from Amethiststraat 31to Zilverlaan 43.