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How is navigational strategy preference associated with navigational abilities in a virtual environment resembling the real world?

Master Thesis

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Abstract

With regard to navigation ability a dichotomy between egocentric and allocentric strategies of navigation has been proposed. Although research indicates that the use of both strategies occurs in parallel people nonetheless prefer using one strategy over the other. This study investigated the relation between strategy preference and navigational abilities regarding that strategy. To assess strategy preference a virtual maze was used, to measure navigational abilities a virtual environment was used to measure navigational abilities such as route memory, estimating distances, sense of direction, and locating landmarks. Results indicated that strategy preference was not related to increased navigational abilities favoring that strategy. This finding emphasizes once more that navigation ability is not dependent on a single factor but involves a range of different cognitive factors.

Navigation behavior of animals has been subject of fascination for many years. Some birds are known to fly thousands of miles to the same breeding ground every year. Even animals as little as ants can travel thousands of times their own body length through a homogeneous environment like a desert and still be able to accurately navigate their way back to their nest (Wehner, 2003). For humans the ability to orient and navigate through familiar and unfamiliar environments is just as crucial.

To be able to accurately navigate spatial knowledge about the environment is needed. This spatial knowledge can be external, like for example using a map to find your way through town. Internal knowledge on the other hand is formed out of multisensory processes. Sensory information such as optic and vestibular cues, computational mechanisms such as route planning and spatial representations such as self-position and orientation are all involved in forming spatial knowledge and need to be integrated and manipulated flexibly to guide navigational behavior (Wolbers & Hegarty, 2010). Locations and objects in the external world can be mentally represented in two ways, depending on the orientation of the underlying reference frames. Egocentric representations are encoded relative to the observer and are therefore observer-dependent. When the observer moves through the environment the positions of objects and landmarks are updated relative to the observer (Klatzky, 1998; Burgess, 2008). By contrast, allocentric representations are observer-independent meaning that objects and landmarks are encoded relative to each other, much like a mental equivalent of a Cartesian coordinate system (Klatzky, 1998; Burgess, 2008; Arleo & Rondi-Reig, 2007). To accurately navigate information from these reference frames need to be stored and updated in memory (Wolbers et al., 2004; Wolbers & Buchel, 2005), as Janzen et al. (2008) showed that memory consolidation was linked to improved navigational skills. One can understand that due to the great amount of factors that contribute to navigation abilities great differences in individual navigation abilities exist.

The dichotomy between egocentric and allocentric spatial representations forms the basis for two distinct navigation strategies; egocentric and allocentric navigation strategies. To navigate using an egocentric navigation strategy route knowledge needs to be acquired (Thorndyke & Hayes-Roth, 1982; Golledge, 1999; Allen, 2004). Route knowledge entails an internal representation of the actions needed to travel from one place to another. Information about the order of certain choice points, like landmarks, and the appropriate action that needs to be taken at each choice point, such as turning left, make up route knowledge (Siegel & White; 1975; Montello, 1998). In essence this can be seen as a sequence of stimulus-response pairs allowing for navigation along a known pathway, and typically only in one direction (Kuipers, 1978). Navigating using route knowledge can be very efficient in familiar and unchanging environments but limits the navigator considerably in dynamic environments and taking novel paths, such as shortcuts. In such a case, survey knowledge, information that needs to be acquired using an allocentric strategy would be better suited. Survey knowledge can be seen as a more flexible representation of the environment (Klatzky et al., 1990; Montello, 1998; Allen, 2004). Tolman (1948) argued that mice were able to create 'cognitive maps', which indicated routes and paths and environmental relationships to find their way through a maze. This term suggests that survey representations are akin to a real map when navigating, which is not necessarily the case. We therefore choose to define survey knowledge as an orientation-independent internal representation of the environment, which means spatial relationships between objects (like distances and directions) can be inferred from any perspective (Wolbers & Hegarty, 2010). Siegel & White (1975) argued that the forming of survey knowledge is facilitated by the amount of exposure one has to the environment. Since then several studies have shown that survey knowledge can even be acquired with little exposure and in large environments (Holding & Holding, 1989; Montello & Pick, 1993). The division between egocentric and allocentric reference frames in navigation might follow a well-known neuropsychological distinction between dorsal and ventral visual processing streams (Goodale & Milner, 1992; Milner, 1999; Burgess, 2006). However, increased activity within these networks is only relative depending on the preferred frame of reference, with widespread overlapping cortical networks involved for navigation in general (Gramann, Müller, Schönebeck, & Debus, 2006).

Research has shown that the acquisition of both egocentric and allocentric strategies occurs in parallel and that strategy preference is influenced by factors such as the environmental information that is available and familiarity with the environment (Igloí, Zaou, Berthoz, & Rondi-Reig, 2009; Foo et al., 2005; Etchamendy & Bohbot, 2007; Hölscher, 2009). However, to our knowledge little is known on how strategy preference is related to performance on navigational tasks requiring the specific use of egocentric or allocentric information.

Over the years several different paradigms have been developed to assess route finding and navigation strategies in animals, primarily in rodents. Maze designs such as the T-Maze, Morris Water Maze or the Radial Arm Maze have proven to be reliable tools to study animal spatial memory and learning (Olton & Samuelson 1976; O'Keefe & Nadel, 1978; Olton, 1979; Morris 1981). Since then numerous adaptations of these mazes have been made, such as changing the cues shown in- and around the maze (Babb & Crystal, 2003). More recently Rondi-Reig (2006) introduced the Starmaze to distinguish between egocentric and allocentric memories in mice. Although these different mazes have been used extensively in animal research less research with these mazes has been done in assessing human navigational behavior. It therefore remains unclear to what extent the findings from animal studies can be generalized to humans. Recently, Mennenga et al. (2014) have shown that a full-sized Radial Arm Maze to fit for human proportions can be used to effectively evaluate factors that contribute to human navigational ability such as spatial abilities and working memory. However, such a room-sized instrument has its limitations: it can be costly, impractical and is less flexible to manipulate the environment to simulate for different conditions.

To overcome some of the limitations of a full-sized maze a new paradigm was introduced by Igloí et al. (2009) to study the parallel acquisition of egocentric and allocentric navigation strategies in humans. Inspired on the Starmaze they created, using a virtual environment (VE), a virtual version of the Starmaze calling it the Virtual Starmaze (VSM). It consisted of five alleys converging into a central pentagon in which participants had to navigate to a hidden goal. In between the alleys five unique landmarks were visible to facilitate orientation.

Not much research has been done on the relationship between navigational strategy preference and navigational performance requiring the specific use of egocentric or allocentric information. We therefore aimed to find out if strategy preference on the Virtual Star Maze task (VSM) was related to different patterns of performance on navigational tasks. We did this by creating a VSM based on the one designed by Igloi et al. (2009) to distinguish between egocentric and allocentric strategy users. Furthermore we designed six navigation assessment (NA) tasks using a VE. Numerous studies have shown that in VEs route and survey knowledge can be acquired (Gramann et al., 2005; Waller, Knapp & Hunt, 2001; Witmer, Bailey, Knerr & Parsons, 1996; Gillner & Mallot, 1998; Richardson, Montello, & Hegarty, 1999; Rossano et al., 1999; Waller et al., 2001; Witmer, Sadowski, & Finkelstein, 2002). The tasks were designed to measure factors contributing to navigation abilities such as route memory, route knowledge, map knowledge and pointing to unseen locations. Each task consisted of two conditions, with the egocentric condition from a fist-person perspective and the allocentric condition from a top-down perspective.

The aim of this study was to investigate if strategy preference of navigation on the VSM was associated with different performance on the egocentric and allocentric conditions of the NA tasks. We reasoned that people show increased performance on the condition of each task that corresponded with their preferred strategy. This led us to the prediction that people who preferred using an egocentric strategy on the VSM would perform significantly better on the egocentric condition in comparison to the allocentric condition of each NA task. Vice-versa we predicted that people who prefer using an allocentric strategy on the VSM will perform significantly better on the allocentric condition in comparison to the egocentric condition of each NA task.

Insight in the relationship between strategy preference and navigational performance can be valuable as research shows that navigation impairment, especially the use of an allocentric strategy, occurs in the early stages in the development of Alzheimer’s Disease (AD)(Hort et al., 2007). The different manifestations of spatial navigation impairments in AD and other cognitive impairments can be used to distinguish between different neurodegenerative or cognitive deficits in the early stages of the disease. While traditional neuropsychological tests may not be sensitive enough to discriminate between AD and cognitive deficits from other etiologies in the early stages of the disease insight in how strategy preference is related to navigational performance could be a helpful addition in detecting AD early on. Deficits in orientation and navigation skills are also present in patients after a traumatic brain injury (Maguire, Burke, Phillips, & Staunton, 1996). The VSM could be used to assess strategy preference so that rehabilitation could be focused on increasing the skills regarding the preferred strategy to compensate for deficits. Additionally the navigational tasks could be used to objectify the improvement of the skills regarding the preferred strategy. Furthermore, the VSM and navigational tasks could be easily accessed by patients at home enabling health care professionals to monitor disease progress more closely and adapt treatment accordingly.

Methods

Participants

A total of forty-eight people participated in this study; two participants were excluded for analysis due to an unclear strategy use. In this study forty-six participants (7 men; 39 women) from the Netherlands aged 18 to 29 years (*M* = 22.22, *SD* = 3.18) were included for analysis. Participation was voluntary and participants were mainly students recruited through an online platform from Leiden University's Social Sciences Faculty, other participants were recruited by flyers and bulletin boards in the Leiden University's Social Sciences Faculty. Only participants of at least an undergraduate level of education were included. Some participants from Leiden University received course credit for their participation. Students and other participants who did not participate for course credit received a monetary compensation of six Euros an hour. Participants with a history of psychiatric complaints were excluded prior to the study.

Materials

Both the VSM task and the NA tasks were shown on a laptop with a 1920 by 1080 pixel screen resolution. Participants sat behind a desk approximately 50 cm from the screen and could use a mouse and keyboard to interact with the laptop.

Virtual Star Maze. Rondi-Reig (2006) showed that a modified version of the Morris water maze can be very useful in assessing the difference between ego- and allocentric strategies in mice. Igloí et al. (2009) developed a virtual version from this 'star maze' to effectively investigate the parallel acquisition of egocentric and allocentric strategies. In Blender v2.0 we developed our own VSM after the virtual star maze used by Igloí et al. (2009). The VSM was made out of ten interconnected alleys, five alleys forming a central pentagon and five alleys radiating from the angles of the central pentagon. Participants explored the maze in first-person perspective and were able to perform rotations and move around freely throughout the maze with the arrow keys on the laptop. Pressing the up or down arrow key resulted in motion through the virtual environment in the corresponding direction. Pressing the left or right arrow key resulted in corresponding rotational movement around the z-axis. Motion only took place when the button was pressed. The exact position of the participant was recorded in a Cartesian coordinate system every 100 ms, enabling us to analyze the path taken in the VSM. To allow for orientation environmental cues were visible between the ends of the five radiating alleys. These landmarks were each presented twice (two distinct forests, a mountain, an antenna and a mountain paired with an antenna) to stimulate participants to encode spatial relationships between these landmarks. Participants had five practice trials to find a hidden goal at the end of one of the alleys, as Igloí et al. (2009) showed that performance was optimal after five trials. Finding the hidden goal was rewarded with an on-screen ‘Bravo’. The sixth trial was a probe trial in which participants were placed at a different position within the maze and were asked to find the hidden goal. The view at the beginning of the probe trial was very similar to that of the training trials prompting participants to use the same strategy as in the training trials. Participants could reproduce the same sequence of body turns, thus using an egocentric strategy, or use environmental cues, thus using an allocentric strategy, to find the hidden goal. This means that the use of either an egocentric or allocentric strategy lead to finishing in different alleys in the maze. Both outcomes were rewarded with a ‘Bravo’. We used this to distinguish between egocentric and allocentric navigators. For a detailed description of the criteria we used to distinguish between egocentric and allocentric navigators we refer to the procedure section.

Navigation Assessment. For both conditions of the NA tasks participants watched a video of a route being travelled through a virtual 3D-town modeled after the real town of Tübingen, Germany. It was designed in Blender and consisted of 3D-buildings (e.g. shops, houses), streets and squares.

In the *egocentric* condition participants watched the route being travelled through the town viewed from first-person perspective (Figure 1). The video was approximately eight minutes long and along the route eight different crossings were passed. At each crossing the video stopped for a moment and took a look to the left and right. Right after the video was shown participants had to complete six different tasks, made in Eprime 2.0, regarding the video they just had seen.

In the *allocentric* condition participants watched the route being travelled through the same town, but in top-down view (Figure 1). A red arrow was used as an indicator for direction of the path that was being travelled. Along the route twenty-one easily recognizable 200 by 200 pixel icons of different landmarks (shops, parks etc.) were visible. The video was approximately six minutes long and along the route eight different crossings were passed. Like the egocentric condition participants were given six different tasks after the video was shown. To correspond with allocentric condition the screenshots in the tasks were presented from a top-down view. In the procedure section we will discuss the tasks for the *egocentric* and the *allocentric* condition in-depth.

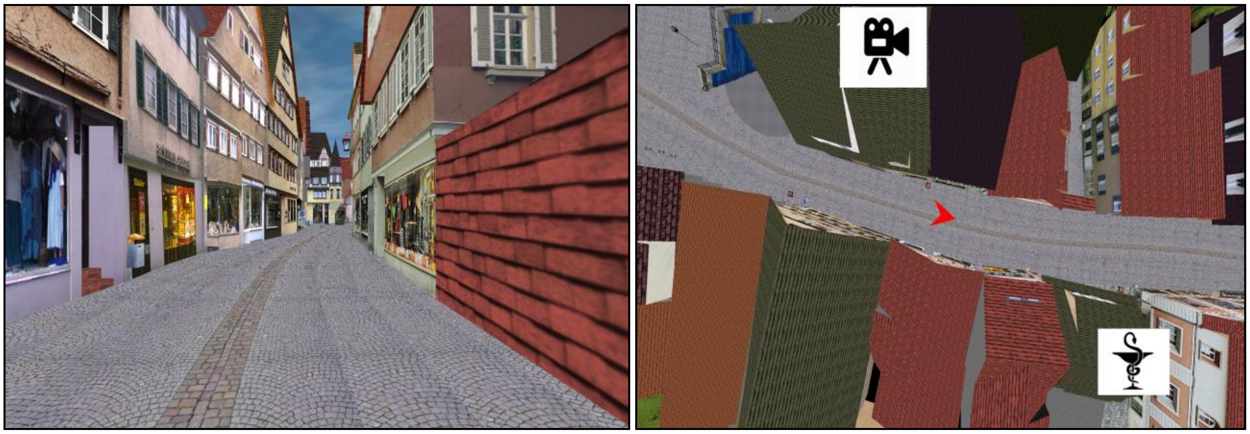

Figure 1. *Egocentric and allocentric condition NA video's. On the left: screenshot of the egocentric condition of the route being travelled in first-person perspective in the NA video. On the right: screenshot of the allocentric condition of the route being travelled from top-down perspective in the NA video, the arrow points in the direction that is being travelled.*

<u>*Design*</u>

The data for this study was collected as part of a larger study which consisted of two points of measurement, with a two week period between the first (T0) and the second point (T1) of measurement. To avoid possible training effects only data from T0 was used for this study.

As a result of the repeated measures design of the larger study the VSM task was administered at T0 and T1. To control for practice effects two versions (A and B) of the VSM were designed, one of which was a mirrored version of the other. Each condition of the NA tasks was also administered at T0 and T1, meaning that participants watched a total of four videos (both egocentric and allocentric condition at T0 and T1). To control for practice effects four different routes for the NA videos were made. The order of the VSM tasks, conditions of the NA tasks and routes of the NA tasks were counterbalanced over T0 and T1.

<u>*Procedure*</u>

Participants who signed up for the study were given a letter with information about the study, for any questions they were able to contact the researcher by e-mail. Upon entering the room participants were told that the study investigated navigational abilities and if these abilities are trainable. Participants were informed the study consisted of questionnaires, a short game, two videos, tasks regarding the videos, orientation- and (spatial) memory tasks. A short break would be given after the NA tasks. After explanation participants signed an informed consent. A debriefing about the goals of this study took place after T1.

Instructions Virtual Star Maze. Participants were told to make movements through the environment in order to find a goal which would always be in the same place: at the end of one of the radiating alleys. Furthermore, they were told that the goal had no visible distinction but when reaching it a 'bravo' would appear which indicated the end of the trial. The environment would not change during the experiment and they had to do the task a couple of times. The existence of practice and probe trials was not mentioned. For each trial a maximal time limit of 120 seconds was allowed. If participants failed to reach the goal within the time limit the next trial was started.

To distinguish between egocentric, allocentric or mixed strategy navigators we firstly looked at which alley participants finished. Participants using an egocentric navigation strategy can be characterized by following the same route as in the training trails by reproducing the same sequence of body turns. Participants using an allocentric strategy to navigate through the maze could be characterized by following a different route in the probe trial by using environmental cues. Further distinction between egocentric and allocentric navigators could be made by the amount of rotations participants performed. Egocentric navigators tended to perform little rotations around the z-axis throughout the maze whereas allocentric navigators tended to perform large rotations around the z-axis at the start of the probe trial. Mixed strategy navigators could be characterized by using a combination of both egocentric and allocentric strategies. In general they performed the same sequence of body turns as for egocentric navigators but corrected their route using environmental cues to finish in either the egocentric or allocentric alley. This lead to a pattern of few rotations around the z-axis at the start of the probe trial and more rotations in the central parts of the maze.

The deciding factor to distinguish between egocentric, mixed or allocentric navigators was the alley in which they finished in the probe trial and which route they took to get there. Taking the most optimal route to get to either the egocentric or allocentric goal alley would lead to being characterized as being either an egocentric or allocentric navigator. Using a less optimal route to reach the goal alley (either the egocentric or allocentric alley), such as walking around the entire central pentagon, would lead to being characterized as a mixed strategy navigator.

Instructions Navigation Assessment. Participants were told for both the egocentric and the allocentric conditions of the NA that they were about to watch a video of a route being travelled through a virtual town. Furthermore they were told to pay good attention to the surroundings, the route being travelled and their orientation during the travelled route because afterwards they would be given tasks regarding the video. For all six NA tasks participants were given instructions on the screen and were able to ask the researcher questions if the instructions were not clear. We will now discuss the NA tasks in-depth.

To assess temporal memory for the route being traversed, an important factor in acquiring in route knowledge, the *Route Memory* task was designed. In this task participants were asked to indicate for each of the eight crossings in which direction the route on the video continued. We presented a 4 by 8 sized grid in which participants were able to indicate with the mouse cursor if the video went left, right or straight ahead. No screenshots of the crossings or other cues were shown, forcing participants to retrieve each turn from memory alone. Performance was scored as the number of correct answers divided by the total number of trials.

The *Route Recognition* task was also designed to assess route knowledge. Unlike the *Route Memory* task participants were presented a 1286 by 846 pixel screenshot of a point along the travelled route as a visual cue. Furthermore, the screenshots were not presented in a chronological order. With the arrow keys of the keyboard (laptop) participants were able to indicate whether the route shown in the video continued straight ahead, left or right from the point presented in the screenshot. The *Route Recognition* task consisted of eight trials. Performance was scored as the number of correct answers divided by the total number of trials.

To assess participants' Euclidian distance knowledge the *Euclidian Distance Estimation* task was designed. For this task participants were presented a 630 by 420 pixel screenshot in the middle of the screen of a point along the travelled route. Below two other 630 by 420 pixel screenshots were presented, one outlined with a blue border and one outlined with a yellow border. On the keyboard two keys were covered with stickers of corresponding colors with which participants had to indicate for which of the two screenshots the Euclidian distance was the shortest to the third screenshot. The *Euclidian Distance Estimation* task consisted of eight trials. Performance was scored as the number of correct answers divided by the total number of trials.

Global orientation and sense of direction was measured by the *Orientation to Start* task. In this task participants were presented a 1286 by 846 pixel screenshot of a point along the travelled route. Using an 'arrow circle' participants had to point in the direction of the starting point of the travelled route. According to Montello et al. (1999) pointing with a dial, like an arrow circle, can be used to externalize people's knowledge of egocentric directions. The arrow circle consisted of a piece of plywood with a magnetic layer inside on which a circle was drawn. In the middle of the circle a steel arrow was stuck onto the plywood with a magnet. The numerical values of the degrees were covered and only visible for the researcher. The arrow circle was placed straight in front of the participants in a way that the arrow circle and the screen were aligned. Next, participants had to turn the arrow in the direction to where they thought the starting point of the travelled route was. In some screenshots the starting point could be seen in others not. After each trial the arrow was reset by the researcher to the 0 degrees position (straight ahead). The *Point To Start* task consisted of eight different trials. Performance was scored as the absolute error between the estimated direction and the correct direction averaged over trials, as it most strongly relates to the probability of a person pointing within a range around the correct answer on any trial (Spray, 1986).

The *Orientation to End* task was exactly similar to the *Orientation To Start* task except different screenshots were shown and participants had to point to the end point of the travelled route. Performance was also scored as the absolute error between the estimated direction and the correct direction averaged over trials.

The acquisition of survey knowledge was assessed by the *Landmark Placement* task. For this task participants were shown a 960 by 720 pixel screenshot of a point along the travelled route. After each screenshot participants were shown a 1920 by 1071 pixel map of the town with a 161 by 161 pixel sized picture of the screenshot visible in the left bottom corner of the screen. With the mouse cursor participants were asked to indicate the location of the screenshot on the map. The *Landmark Placement* task consisted of eight different trials. Performance was scored as the absolute error between the estimated place of the landmark and the correct place of the landmark in pixels averaged across trials.

To fit for the allocentric condition the tasks were slightly adjusted. For the *Route Memory* task participants were asked to imagine the turns they had taken from a top-down view. Screenshots for the *Route Recognition* task were presented in a top-down view. For both the *Euclidian Distance Estimation* task and the *Landmark Placement* task instead of screenshots icons of the landmarks along the route were shown. For the *Orientation to Start* and the *Orientation to End* tasks the screenshots were presented from a top-down view. The arrow circle was also held up right next to the screen by the researcher to make sure no mental spatial translations needed to be performed by the participants.

Except from these few differences regarding the presentation of the egocentric and allocentric tasks the outcome measures were the same, thus making it possible to compare the outcomes of the egocentric and allocentric conditions of the same task.

Statistical procedure

Preliminary results showed that a sizeable portion of navigators was classified as mixed strategy (n = 13) in comparison to egocentric (n = 24) and allocentric (n = 9). The criteria we employed to distinguish between egocentric and allocentric navigators, the alley in which they finished the probe trial, were clearly defined and unambiguous. Almost all other strategies used on the VSM were classified as mixed strategy navigators meaning that within the mixed group strategies to solve the VSM varied greatly. The sizeable portion and the nature of mixed strategy navigators led us to the conclusion to exclude the mixed strategy navigators from our analysis of variance, to provide for a clearer comparison of performance on the NA tasks. Meaning that only performance on the NA tasks between the more clearly defined egocentric and allocentric navigators was compared, allowing us to draw conclusions from our results more strongly.

A two-way repeated measures ANOVA was conducted in SPSS for each NA task separately to compare different strategies on the VSM with performance on the NA task. The preferred *Strategy* on the VSM was the between-subjects independent variable (IV) and consisted of two levels (Egocentric and Allocentric). The *NA* task type was the within-subjects IV and also consisted of two levels (Egocentric and Allocentric). The dependent variable (DV) was the performance on the NA tasks. We were especially interested if an interaction effect occurred between *Strategy* and *NA* task. The rejection level for all our hypotheses was set at p = .05.

Analysis of our dataset showed that our data did not meet the assumptions of normal distribution for performing a two way analysis of variance. However, to our knowledge no non-parametric equivalent of a two-way repeated measures ANOVA test is available, we therefor accepted to violate the assumption of normal distribution to test our hypotheses. To be able to interpret our results more strongly we opted to perform additional analyses as a sensitivity test. For each participant we calculated the standardized mean difference score of performance between both conditions for each of the *NA* tasks and used a non-parametric t-test (Mann Whitney U test) to compare performance of egocentric and allocentric navigators. If similar results are found, this means that violating the assumption of normality did not affect the statistical validity of our results.

Results

Performance on each of the *NA* tasks was subjected to a two-way analysis of variance. Preferred *strategy* consisted of two levels (Egocentric, Allocentric) and NA task also consisted of two levels (Egocentric, Allocentric). All results were statistically significant with an alpha of .05. Descriptive statistics for preferred *Strategy* (egocentric, mixed, allocentric) and for each *NA* task (egocentric and allocentric) are shown in Table 1. As mentioned earlier mixed strategy navigators were excluded from our analyses of variance. One participant was excluded from analysis on the route memory task because of no available data on the egocentric condition.

Table 1

Sample Sizes, Means and Standard Deviations for each NA Task

			Task Type	
			Egocentric	**Allocentric**
NA Task	**Strategy**	***n***	***M (SD)***	***M (SD)***
Route Memory	Egocentric	24	71.35 (23.16)	67.71 (23.29)
	Mixed	12	57.29 (31.29)	47.92 (23.13)
	Allocentric	8	65.63 (25.66)	68.75 (25.00)
Route Recognition	Egocentric	24	71.88 (16.99)	80.21 (15.60)
	Mixed	13	63.46 (19.41)	74.04 (24.72)
	Allocentric	9	73.61 (20.20)	72.22 (22.34)
Euclidian Distance Estimation	Egocentric	24	70.83 (21.39)	69.27 (16.06)
	Mixed	13	55.77 (23.17)	66.35 (11.84)
	Allocentric	9	55.56 (27.32)	72.22 (10.42)
Orientation to Start	Egocentric	24	46.17 (19.78)	72.34 (55.78)
	Mixed	13	53.81 (12.84)	51.71 (39.84)
	Allocentric	9	37.53 (17.16)	59.12 (48.85)
Orientation to End	Egocentric	24	53.41 (16.10)	48.62 (29.18)
	Mixed	13	54.71 (21.30)	46.96 (24.13)
	Allocentric	9	47.60 (26.93)	40.06 (25.80)
Landmark Placement	Egocentric	24	139.23 (54.60)	108.70 (67.77)
	Mixed	13	160.11 (62.22)	145.46 (62.75)
	Allocentric	9	95.47 (55.00)	115.31 (83.54)

Note. NA Task = Navigation Assessment Task. Route Memory, Route recognition and Euclidian Distance Estimation scores represent percentage of correct answers. Orientation to Start and Orientation to End scores represent mean absolute error in degrees averaged over trials. Landmark Placement scores represent mean absolute error in pixels averaged over trials.

Testing for differences of performance between conditions of the *Orientation to Start* task showed a significant main effect for task type, indicating better performance on the egocentric condition (M = 43.81, SD = 19.24) than on the allocentric condition (M = 68.73, SD = 53.56). Table 1 shows no other statistical significant main-effects for task type have been found, meaning that performance was not better on either the egocentric or allocentric condition on each of the five other NA tasks. Likewise, no statistical significant main-effects for strategy have been found, meaning that performance was not better for either the egocentric or allocentric strategy navigators on all six *NA* tasks.

Table 2

*Two-way Analysis of Variance: Main-Effects for Task Type, Main-Effects for Strategy and Interaction-Effect Task Type*Strategy*

	Task Type			**Strategy**			**Task Type*Strategy**		
NA Task	***F(df)***	***p***	η^2	***F(df)***	***p***	η^2	***F(df)***	***p***	η^2
Route Memory	0.00 (1,30)	.972	.000	0.14 (1,30)	.707	.005	0.21 (1,30)	.653	.007
Route Recognition	0.84 (1,31)	.365	.026	0.29 (1,31)	.594	.009	1.65 (1,31)	.208	.051
Euclidian Distance Estimation	2.05 (1,31)	.162	.062	1.29 (1,31)	.266	.040	2.98 (1,31)	.094**	.088
Orientation to Start	4.47 (1,31)	.043*	.126	0.96 (1,31)	.334	.030	0.04 (1,31)	.841	.001
Orientation to End	0.75 (1,31)	.393	.024	1.30 (1,31)	.263	.040	0.04 (1,31)	.849	.001
Landmark Placement	0.09 (1,31)	.762	.003	1.08 (1,31)	.307	.003	2.07 (1,31)	.161	.062

Note. NA task = Navigation Assessment Task

* $p < .05$ ** $p < .10$

Lastly, no statistical significant interaction effects for any of the six NA tasks were found when using parametric (two-way analysis of variance, Table 2) as well as non-parametric (Mann Whitney U test, Table 3) tests. Indicating performance did not improve on the condition that corresponded with the preferred strategy of navigating. However, on both tests an interaction trend towards significance on the *Euclidian Distance Estimation* task was found. Post-hoc comparisons with Bonferroni correction indicated a trend towards significance for allocentric navigators, $F(1,31) = 3.43$, $p = .074$, $\eta^2 = .100$, indicating increased performance on the allocentric condition of the *Euclidian Distance Estimation* task in comparison to the egocentric condition. For egocentric navigators no significant differences between task conditions were found.

Table 3

Mann-Whitney U test comparing standardized mean differences between egocentric and allocentric navigators for each task.

NA Task	**Task condition**	**Median**	**Mean Rank**	**Mann-Whitney U**	**Asymp. Sig. (2-tailed)**
Route Memory	Egocentric	0.80	15.67	76.00	.383
	Allocentric	1.10	19.00		
Route Recognition	Egocentric	1.00	18.25	78.00	.197
	Allocentric	1.00	13.67		
Euclidian Distance Estimation	Egocentric	1.00	15.08	62.00	.062*
	Allocentric	1.25	22.11		
Orientation to Start	Egocentric	0.77	17.08	106.00	.936
	Allocentric	0.76	16.78		
Orientation to End	Egocentric	1.26	16.98	107.50	.984
	Allocentric	1.29	17.06		
Landmark Placement	Egocentric	1.50	17.94	85.50	.363
	Allocentric	1.54	14.50		

Note. NA Task = Navigation Assessment Task

* $p < .05$

Discussion

In humans, a dichotomy in navigation strategy use can be made; egocentric and allocentric strategies. For an egocentric, observer-based strategy route knowledge is needed, which entails an internal representation of the actions needed to travel from one place to another. Using an allocentric, environment-based, strategy relies on survey knowledge which can be defined as an orientation-independent internal representation of the environment (Wolbers & Hegarty, 2010). Research suggests that the acquisition of egocentric and allocentric navigation strategies occurs in parallel (Igloi et al., 2009), but people nonetheless prefer one strategy to the other. Different paradigms to assess animal navigation behavior and strategy choice have been developed (Olton & Samuelson 1976; O'Keefe & Nadel, 1978; Olton, 1979; Morris 1981), however far less is known on how strategy preference is associated with navigational performance in humans. We used the Virtual Star Maze (VSM), a virtual adaptation of the Starmaze used by Rondi-Reig (2006), to distinguish between egocentric and allocentric navigators. Furthermore, we created several navigation tasks with an egocentric and an allocentric condition to measure factors contributing to navigation abilities such as route memory, map knowledge and pointing to unseen locations. We predicted that strategy preference on the VSM would be related to increased performance on navigation tasks involving that particular strategy.

Our results indicate that strategy preference of navigating is not related to increased navigational abilities regarding that strategy, meaning that regardless of the strategy one prefers to use people are able use navigational knowledge regarding their non-preferred strategy equally well. These results suggest that navigation is not dependent on a single factor like perspective preference but involves a range of different cognitive factors (Wolbers & Hegarty, 2010). Moreover, factors associated with navigation ability in general such as memory of the route travelled, map knowledge and maintaining a sense of direction might not be specifically associated with a certain perspective. People may therefore be able to switch between reference frames with relative ease, depending on factors such as the information that is available and familiarity with the environment (Foo et al., 2005; Etchamendy & Bohbot, 2007; Hölscher, 2009).

We have to take into consideration the substantial proportion of mixed strategy navigators when distinguishing between the strategies used on the VSM. The criteria we employed to distinguish between egocentric and allocentric navigators, the alley in which they finished the probe trial, were clearly defined and unambiguous. However, the criteria used to classify mixed strategy navigators were less restricted. Performing the same sequence of body turns as for egocentric navigators but correcting their route using environmental cues to finish in either the egocentric or allocentric alley would lead to being characterized as mixed strategy navigators. Therefore, by definition, mixed strategy navigators did not use a distinct egocentric or allocentric strategy. This is reflected in the great variability of routes travelled on the VSM by mixed navigators. For instance, some made an entire 360-degree rotation around the central pentagon to finish in the egocentric alley whereas others made an entire 360-degree rotation to finish in the allocentric alley. Others partially used an egocentric strategy but entered one alley before the target alley, thus missing the target. Some corrected themselves to quickly find the goal alley, whereas others managed to find the goal alley by trial-and-error without a systematic approach. Systematically checking each alley one-by-one is another strategy used by mixed navigators meaning that finishing in either the egocentric or allocentric alley in the probe trial was dependent only on which direction they systematically checked each alley. This wide variety of strategies used on the VSM is in line with the study of Igloí et al. (2009), as they showed a substantial proportion of navigators could be classified as using a mixed strategy. They hypothesized that the substantial proportion of mixed strategy users provided support for the theory that updating of egocentric and allocentric navigation strategies occur in parallel (Burgess, 2006; Igloí et al., 2009). Our findings further strengthen the idea of parallel updating of navigation strategies. Moreover, the lack of any differences in navigational performance associated with strategy preference might indicate that both strategies are even at play in parallel in environments resembling the real world.

Evaluation of the difference on performance on the different navigation tasks suggested that for maintaining a sense of direction the different routes impacted performance. On two of the four routes the average pointing error for all participants combined was between twenty and thirty degrees, whereas on the other two routes the average pointing error was over a hundred degrees. Indicating great variations of performance between the different routes. All routes had a similar travel distance, equal amount of intersections and landmarks, no overlaps in the same direction and a maximum of only one overlap in the opposite direction. Our results suggest that, even within the same town, the route being travelled plays an important role in one’s ability to accurately maintain a sense of direction. Our results indicate most accurate pointing on the routes that were aligned the most with the point of reference, the route which was misaligned the most from the point of reference showed the worst pointing accuracy. This might reflect a phenomenon of decreasing pointing accuracy when a reference point is misaligned with one’s own frame of reference (Werner & Schindler, 2004; McNamara, Rump & Werner, 2003; Roskos-Ewoldsen, McNamara, Shelton & Carr, 1998). An important factor to take into consideration in designing tasks measuring sense of direction might therefore be the degree of alignment with the point of reference. Furthermore, our results do not indicate an impact of the different routes on the ability to memorize the route travelled or the ability to locate landmarks on a map. Taken together, our results show once more the large variability in navigation abilities but also the difficulty in designing tasks measuring navigational abilities. Equal groups of men and women would have provided for stronger interpretation of our results. As research has shown that men and women show differences of performance on navigation tasks (Sandstrom, Kaufman & Huettel, 1998; Moffat, Hampson & Hatzipantelis, 1998; Montello, Lovelace, Golledge & Self, 1999). Also, the inclusion of more allocentric navigators would have been needed for stronger interpretation of our results. For future research these points should be taken in consideration. Additionally, research on how memory processes affect the ability to maintain a sense of direction in real-world environments might provide insights in how to improve tasks measuring sense of direction. Concluding, research on how strategy preference is associated with the ability to estimate distances might also be fruitful.

In summary, our study showed that navigational performance is not affected by strategy preference, meaning that people are able to use navigational knowledge regarding their non-preferred strategy equally well in comparison to their preferred strategy. Furthermore, our results on the VSM were comparable to the results found by Igloí et al. (2009) providing further support for their theory of parallel acquisition of egocentric and allocentric navigation strategies. Further research into navigation task characteristics and how specific navigational abilities contribute to performance may help to improve methods of assessing navigation abilities such as sense of direction. Additional research into how cognitive impairments as a result of traumatic brain injury or neurodegenerative diseases such as Alzheimer’s Disease affect performance on navigational tasks might provide valuable insights and help to discriminate between cognitive deficits from different etiologies. In conclusion, our study once more showed a great variability in navigational abilities exist and that navigational performance is not dependent on a single factor. Herein lies the challenge for studying navigation behavior in humans.

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