A different point of view

The role of working memory and sense of direction in the transformation of egocentric to allocentric survey knowledge.

Name: Sjoerd Braaksma

Email: s.w.braaksma@students.uu.nl

Student number: 3518434

Supervisor

Name: Michiel Claessen

Contact details: M.H.G.Claessen@uu.nl

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Abstract: This study examined how participants performed on two methods of testing allocentric survey knowledge. A within-route method of testing, and a between-route method of testing. The involvement of different working memory components on performance was examined. This was done using a dual-task method, in which participants learn routes from videos while performing a visual, spatial, or lexical interference tasks or without any interference. Participants were also divided between a good and poor sense of direction group, by their score on a sense of direction questionnaire. This allowed for differences in the involvement of working memory components to be examined for good and poor sense of direction participants. Results showed that performance on the between-route method correlated strongly with other allocentric survey knowledge-type tasks, while the within-route method of testing did not. The between-route method also showed a significant difference between good and poor sense of direction participants, while the within-route method of testing failed to do so. Finally, the different aspects of working memory involved between good and poor sense of direction participants more closely resembled that of earlier research on allocentric survey knowledge on the between-route method. No differences in aspects of working memory conditions compared to their respective control conditions were found on within-route performance. These results provide support for the notion that a between-route method of testing allocentric survey knowledge could be superior compared to a within-route method of testing.

Keywords: egocentric, allocentric, working memory, sense of direction, two-route model

Introduction

You look around you, but you don't know where you are. You keep walking, going on the feeling you recognize this part of town. And in an inexplicable way, you find your way back to your original route. But how did you do it?

Knowing where you are is of essential importance for a living organism. But the entire process of obtaining information from the environment and keeping track of where you are, especially from a bigger perspective, is not yet completely known, leaving a lot of aspects open for research.

When we walk a certain route, in the real or virtual world, we remember it from our own perspective, like a series of snapshots consisting of important landmarks and the routes connecting them (Münzer, Zimmer, Schwalm, Baus & Aslan, 2006). Stankiewicz and Kalia (2007) state that a landmark, in order to be functional, should have three properties. It should be 1) persistent, meaning that it should still be there when a navigator returns to the scene of the landmark. It should be 2) perceptually salient; it needs to be easily detectable and identifiable, and it should be 3) informative, in the way that it gives information about the navigator's position in the environment. In addition, routes are seen as the sequence of landmarks linked by the path connecting them. A route contains minimal information about the 'choice point' landmarks, and merely holds information about the order of landmarks and the routes connecting them (Montello, 1998; Münzer et al. 2006).

The dominant framework (Montello, 1998) states that transforming landmark and route knowledge into a space-oriented mental representation requires a more sophisticated mental process. It not only requires the consideration of multiple perspectives, but also the integration of several kinds of information. This resulting space-oriented representation is called survey knowledge (Münzer et al., 2006; Montello, 1998). A neurological basis for a higher level of sophistication in survey knowledge was found in the research of Corazinni and colleagues (2010). Participants performed a route knowledge learning trial, and a survey knowledge learning trial prior to an fMRI scan. During the scan, brain activation was recorded during subsequent route and survey tasks. The study found that there was some overlap in brain areas used during both types of tasks, showing some overlap in terms of brain areas used in route and survey knowledge. The research shows that route and survey knowledge partially use the same neurological systems and information. In addition, the learning of survey knowledge appeared more complex as shown by a longer practice time to reach the learning criterion. Other brain-imaging studies have found similar results (Graman et al. 2009).

The cognitive function that is responsible for the transformation and integration of acquired spatial knowledge is the working memory. The definition of the working memory Baddeley (2003) provided in his paper is as follows:

> "[…] *the working memory is a limited capacity system, which temporarily maintains and stores information, supports human thought processes by providing an interface between perception, long-term memory and action."*

This model of working memory consists of three components (fig. 1). The phonological loop holds a limit of verbal memory traces in its phonological store, and keeps this information active by rehearsing it through subvocal speech. The visuospatial sketchpad is a limited storage capacity for visual information as well as spatial information. Lastly, the central executive supervises attention and demand towards its two subsystems. In later research, a fourth component, the episodic buffer was added to act as an interface between the working memory systems and long-term memory aspects.

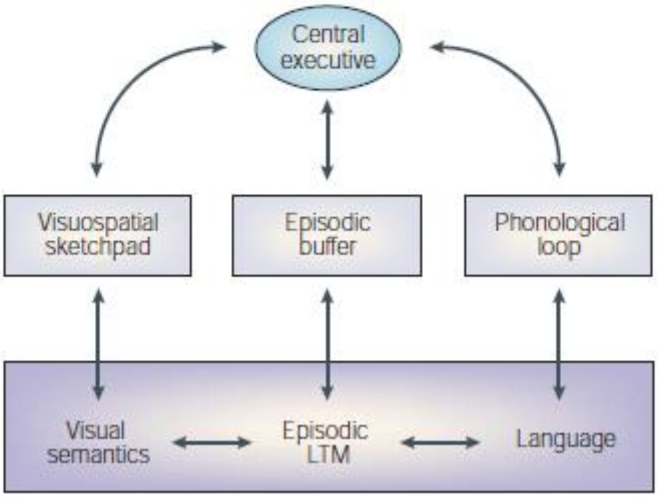

Figure 1: The multi-component model of working memory (Baddeley 2003)

Recently, the acquisition and usage of several types of spatial knowledge and what role the working memory plays in these processes has gained increasing attention from researchers (Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001; Paivio, 2010).

But how does the model of working memory interact with the acquisition of landmark, route and survey knowledge? This is most often tested using the dual-task paradigm (Pashler, 1994). In such a paradigm, one component of working memory is loaded with a simple secondary task while at the same time the participant has to perform a key task. In the case of this paper, the secondary task can be a verbal, spatial or visual one, one task for each part of working memory involved in the primary task. If performance on the key task is impaired in the dual task condition and not in the control condition, it can be stated that the particular subcomponent of working memory is involved in the key task. Most research using the dual task paradigm has found that landmark and route knowledge is encoded in both the spatial and verbal components of working memory (Deyzac, Logie & Denis, 2006; Meilinger, Knauff & Bülthoff, 2008; Garden, Cornoldi & Logie, 2002). Furthermore, research focusing on the modality of information presented, has found that visuo-spatial working memory is prominently used while obtaining survey knowledge from maps as opposed to navigating through the environment (Garden et al., 2002; Coluccia, Bosco & Brandimonte, 2007; Coluccia, 2008). Individual differences in the acquisition of survey knowledge have also been researched. Generally, people who report a good sense of direction perform better on survey-related tasks than those who report a poor sense of direction (Ishikawa & Montello, 2006; Wen, Ishikawa & Sato, 2010; Hegarty, Richardson, Montello, Lovelace & Subbiah, 2002). A limitation however, is that most research has focused on one aspect of wayfinding: either landmark, route or survey knowledge was tested.

But first it is important to know where egocentric and allocentric knowledge fit into the frame of landmark, route and survey knowledge, and strictly define one from the other. Egocentric and allocentric viewpoints fit into this by giving a frame of reference in which route and survey knowledge can be based. Both route and survey knowledge can be represented either egocentrically or allocentrically.

An egocentric viewpoint is always anchored in an egocentric frame of reference (Klatzky, 1998). Its spatial parameters, axis of orientation and its bearing towards other objects is dependent of the viewpoint. It is a so-called person-object relation. An allocentric viewpoint, however, is more flexible and sophisticated. It is independent of any form of egocentric anchor, and is more focused on the spatial relations between objects. This allows allocentric knowledge to be less rigid and more easily manipulated, as it is free to be rotated and viewed from different angles, not being tied to an anchored viewpoint (Friedman, 2005; Werner, Brücker, Mallot, Schweizer & Freska, 1997; Klatzky, 1998). So landmark, route and survey knowledge define the kind of information people can acquire in an environment, and egocentric and allocentric knowledge define the perspectives in which this information can be internally represented.

The study of Wen and colleagues (2013) presents a model of the different components of information processing in route and survey knowledge combined with an egocentric and allocentric perspective, and how this process is different between people with a good and poor sense of direction (SOD). This model is interesting not only as a framework of visuospatial information processing, but also as a way to explain individual differences in not only route and survey knowledge processing, a but also the ability to put this into either an egocentric or allocentric perspective.

The model builds on earlier research by Klatzky (1998), who subdivided spatial information into egocentric and allocentric information, and how processing these two types of spatial information affected good and poor SOD.

Within Wen's research, it is noted that spatial, verbal and visual working memory play a role in transforming egocentric information to allocentric information. Wen's model explains this by proposing that people with a good SOD use egocentric as well as allocentric information in wayfinding, where people with a poor SOD mainly use egocentric information. Also, the encoding process of people with a good SOD differs from that of people with a poor SOD. For people with a good SOD, landmarks and routes are processed in verbal and spatial memory, after which these two memory components combine them into egocentric survey knowledge. All three components of working memory (especially the visual component) are then used to transform egocentric survey knowledge into allocentric survey knowledge. People with a poor SOD have a high degree of sensitivity for egocentric survey knowledge, but fail to acquire allocentric survey knowledge. Because they lack spatial processing for landmarks and routes, they have more difficulty in acquiring egocentric survey knowledge, which in turn gives them insufficient spatial knowledge to acquire allocentric survey knowledge.

Trying to improve upon earlier research, and add to the knowledge base regarding working memory and survey knowledge acquisition, we attempt to answer a few questions and remarks that arise based on these types of studies.

For instance, in most other research studies, participants were presented allocentric questions while they were still in an egocentric perspective. Or participants were asked questions that would not fully call upon someone's allocentric spatial abilities. For instance, having seen one route, a participant had to mentally place himself at a location within that route and point towards another location within the same route. Theoretically, the correct answer can be derived using egocentric survey knowledge alone, as well as allocentric survey knowledge. Both types of information are used alongside each other, rather than exclusively using egocentric or allocentric knowledge (Burgess, 2006). In this research, participants will be shown two routes that overlap partially, to more purely asses a participant's survey knowledge. According to Montello (1998) survey knowledge can be route specific, but is mainly constructed by integrating information from different routes. An aspect of survey knowledge is the direct relational information between points a person has never directly traveled, which in this method is tested, while excluded from single-route methods. Integrating two routes also needs to be done within a spatial framework that extends beyond only the two routes, and the two different perspectives provided by two integrated routes provides more spatial information to facilitate the transformation of spatial knowledge from an egocentric to an allocentric, map-like viewpoint (Maguire, Burke, Phillips, & Staunton, 1996; Klatzky, 1998). This study uses the two-route model to assess survey knowledge in two ways. First, participants are asked to mentally place themselves in one route, and answer questions about landmarks within that route. This way their survey knowledge is tested using the traditional, single-route format. Secondly, participants are asked to mentally place themselves in one route, and answer questions about the other route, in order to more purely asses just allocentric survey knowledge, without the confounding use of egocentric survey knowledge to infer their answer. In order to show this contrast, participants with a good SOD are expected to perform better on both single-route and two-route methods of testing.

However, according to the findings of Wen and colleagues (2013) good SOD participants correctly acquire allocentric survey knowledge, while poor SOD participants do not. Since the two-route model is supposed to measure allocentric survey knowledge more purely, we expect the good and bad SOD difference to be larger in the between-route task. Alongside this, the same procedure as used by Wen and colleagues (2013) and Meilinger and colleagues (2008) is used to gain insight into the mechanisms of working memory involved in acquiring egocentric and allocentric route and survey knowledge. Just as in the study of Wen, we predict participants with a good SOD to perform better than poor SOD participants on both egocentric and allocentric tasks. We also predict that good SOD participants will mostly use spatial working memory to acquire information about the environment, and that the involvement of visual working memory is greater in the acquisition of allocentric than egocentric survey knowledge. Participants with a poor SOD are expected to use all three aspects of working memory to acquire egocentric survey knowledge, and fail to acquire allocentric survey knowledge.

In Wen's study, measures of distance and direction are measured separately. In this study the egocentric and allocentric task will be used with an added direction estimation task, in order to see if performance on the distance estimation task correlates with performance on the direction estimation task, and how this affects participants with good and poor SOD's.

Methods

Participants

This study uses a sample of 60 healthy students. 8 students were excluded due to insufficient performance on the secondary task (scoring less than 80% correct), or because they only chose one of two options consistently on the landmark recognition task. Of the 52 participants, 22 were male and 30 were female. All participants were between 18 and 32 years of age (M = 21, SD = 2,5). participants were divided by means of a questionnaire (Hegarty et al., 2002) into a group with good sense of direction and poor sense of direction, and divided among four secondary task conditions (table 1).

Table 1: distribution of males/females, age and standard deviation of age across conditions and sense of direction scores.

Factor 1: Condition	Male	Female	Age(M)	Age (SD)
Visual	5	8	23	3.17
lexical	5	5	19	2.21
Spatial	10	4	21	2.26
Control	5	10	20	1.69
Factor 2: SOD				
Good SOD	10	14	21	2.29
Poor SOD	8	20	21	2.70

Primary task

In the primary task, participants were shown two route videos in first-person perspective. Each video was shown twice, in the order 1-2-1-2. Before the primary task started, participants were instructed that they were about to see two route videos, which were situated in the same environment and that would cross each other at some point. They were told to pay as much attention to the videos as possible while performing the secondary task.

Route video

The two videos were sped up and stabilized using video editing software. The first video was 150 seconds long and consisted of a route of 490 meters. The second video was 142 seconds long and consisted of a route of 475 meters. Both routes were situated in the same suburban environment, and crossed each other along the centre. Typical buildings consisted of row housing, flats, and small businesses. The routes ran in opposite directions, as to prevent participants from solving between-route tasks relying solely on route knowledge. Each of the routes contained 5 landmarks, with one landmark being shared on the position where both routes cross each other (fig. 2). When the route video arrived at a landmark, the camera would pan towards the landmark, the name of the landmark was shown for 5 seconds, and the camera would pan back to its original position and proceed with the route. The landmarks were chosen on the basis of the three properties of Stankiewicz & Kalia (2007), in that they needed to be typical in a common town or city (store, church, etc.) as well as perceptually salient and informative about the position of the navigator.

Fig 2: Left: overview of the two routes shown during both videos along with position indicators of landmarks. Horizontal is route 1, vertical is route 2. *Right*: example of a landmark used in the route video.

Secondary interference task

Before the primary task was initiated, participants practiced with a secondary task, in order to get accustomed with it before the two tasks were combined. After one or two practice rounds of 5-minutes (until the participant acquired a cumulative percentage correct of 80% or higher) the secondary task was performed alongside the primary task. All tasks used in the interference condition are a modification of the interference tasks used by Meillinger and colleagues (2008) and Wen and colleagues (2013). A control condition was also included, in which participants performed no secondary task.

Visual interference task

The visual task consisted of participants imagining a clock, divided in half along the 9 and 3 hour mark. The visual task consisted of a verbally presented time indication (example: 4:20) presented by means of audio files through a speaker setup. Participants were instructed to imagine a clock, divided in an upper and lower half. After hearing a time indication, the participant had to respond whether the imaginary hands of the clock were in the same imagined half or in different halves, by pressing one of two keys on a keyboard. The times presented would range from 1-12 o'clock, using 5 minute intervals. Times consisting of 3 or 9 hour, and 15 and 45 minute marks were excluded as not to confuse participants.

Spatial interference task

The spatial task consisted of 2 speakers, placed to the left and right of the participant. At random, one of the speakers would produce a sound, after which the participants had to indicate from which speaker the sound came by pressing one of two keys on a keyboard.

Verbal interference task

The verbal task consisted of a lexical decision task, in which participants had to decide if a verbally presented Dutch word was an existing word or not. The list consisted of 100 words and 100 non-words. The words were taken from a database of the 10.000 most frequently used words in the Dutch language, hosted by the University of Leipzig. This list of words was already in Dutch, and needed no further translation. All words containing two syllables were selected. Each word was recorded as a separate audio file. The computer would select a file from the file pool at random, and play it using the two speaker system. The participant responded by pressing one of two keys on a keyboard.

Landmark recognition task

After the participants performed the secondary task while watching the route video, they were instructed to perform the landmark recognition task. In this task, participants were shown photographs from the landmarks presented in both routes. The photographs were snapshot images taken from the route videos, as to present the landmarks in the same orientation as the participant saw them. Participants were then asked to indicate in which route the landmark was shown.

Landmark proximity task

In the landmark proximity task, participants were shown one of the landmark photos at random, and were instructed to imagine themselves standing in the exact spot and orientation the photo was taken in. Then, two photos of different landmarks were shown, and participants had to choose which of the presented landmarks was closest to their imagined location, in straight line distance. The correct choice could be a landmark from the same route as the imagined location, or from a different route as the imagined location.

Landmark proximity and pointing task

Participants then repeated the landmark proximity task, with one addition. Now participants had to indicate the direction of the closest landmark from their imagined position, in addition to choosing which landmark was closest. This is a combination of the distance and direction estimation task used in the study of Schinazi, Nardi, Newcombe, Shipley and Epstein (2013). A dial was used to allow participants to indicate the direction of the closest landmark. On this dial degrees were presented, not visible by the participant, in order to record the chosen direction and compare it to the correct response. This does not require participants to produce an exact gradient and numerical distance, but estimate the spatial orientation of the three landmarks relative to each other. This part is repeated 14 times for different points of reference and landmark combinations (Klatzky, 1998; Wen et al., 2013).

Landmark drawing task

In the landmark drawing task, participants were shown a map overview of the area the two routes were situated in, showing roads and the outlines of buildings. The start and ending points of both routes were indicated on the map. Participants were asked to draw the exact location of the landmarks from both routes on the map. A point was awarded for each correctly placed landmark relative to the position of the roads. All landmarks, except for one, were positioned closely to an intersection and/or starting point of the route videos, making the scoring procedure of a correct placement easier. One exception was the first landmark in the first video, which falls in between the start of the video and an intersection, granting participants far less information about its relative placement on the map. A more lenient scoring procedure was used in this case, where a small area was defined before scoring. If the landmark was drawn within this small area, a point was awarded (Labate, Pazzaglia, & Hegarty, 2013). The acquired points of a participant were added up, granting a minimal score of 0 and a maximum score 7.

Sense of direction questionnaire

Questionnaire for sense of direction: Participants filled out a 'sense of direction' questionnaire. This questionnaire consists of 15 items on a 7-point Likert scale, and a higher total score on the scale indicates a better sense of direction. The questionnaire is a self-report measure about spatial and navigational abilities, sense of direction, preferred way of navigation, and remembering routes. An additional item was added, ‘I usually envision a 2D map in mind when learning a new route’ to measure the tendency to use imagery of participants (Wen et al. 2013). Based on these scores, the entire group of participants is divided into a good and poor group for sense of direction through a median split. The questionnaire was administered after initial testing of the primary and secondary tasks. This questionnaire is a Dutch translation of the Santa Barbara Sense of direction Scale (SBSOD) by Hegarty et al. (2001).

Procedure

Before the primary task was initiated, participants first practiced with the secondary task, in order to get accustomed with it. After this practice phase participants were instructed to perform the primary and secondary task at the same time, as to load the working memory through means of the secondary task, limiting the information of one specific type that can be acquired form the route videos. After this task, participants performed the orientation task, the landmark drawing task, and finally filled out the sense of direction questionnaire.

Statistical analyses

Performance on the secondary task, across conditions was tested using one-way anova procedures. Bonferroni post-hoc analyses were used to identify specific group effects. Differences across the landmark recognition task and landmark drawing task were analyzed using a 4x2 factorial anova. Factor one contained four levels, consisting of the secondary task conditions. Factor two contained two levels, consisting of the good and poor SOD groups. Both factors were treated as between-subject factors. On the landmark proximity task, a third, within-subjects factor was added. This factor consisted of 2 levels, consisting of within-route and between-route performance. This resulted in a 4x2x2Mixed-design anova to not only analyze the difference across conditions and SOD score, but also on within-route and between-route tasks. Further investigation of any interaction effects that might be present were tested using pairwise comparisons. Pearson correlation was used to test the validity of the various measures. An alpha level of .05 was chosen as significant indicator.

Results

Secondary task performance

The percentages of correct responses in the interference task while performing the primary task did not differ significantly across the three conditions, indicating comparable difficulty across tasks (table 2). There was no significant difference found in performance on the practice trial and performance during the primary task $t(36)=1.008$, $p=.320$. There was, however, a significant difference in reaction times found between the spatial interference task and the visual and lexical interference task $F(2, 34)=$ 26,065, $p<.01$. This was however, already accounted for by the difference in inter-stimulus interval. Further examination showed that the difference in performance on the secondary task did not correlate significantly with any of the outcome variables measured, indicating no trade-off between performance and memory of the routes learned ($p<.05$).

Table 2: mean reaction time, practice accuracy, and accuracy during the primary task for all three interference conditions. Standard deviations are presented in parentheses.

	Visual	Lexical	Spatial
Reaction time (ms)	1193	787	330
% correct in learning phase of secondary task	94 (5.3)	83 (7.7)	98 (1.7)
% correct on Route phase of secondary task	92 (5.7)	91 (5.8)	96 (4.9)

Sense of Direction

On the basis of their scores on the SBSOD scale, participants were divided into a group with good and poor SOD, through a median split (Mdn=4.03), across conditions. The good SOD group (N=24) had a mean score of 4.9 and the poor SOD group (N=28) had a mean of 3.1.

Landmark recognition task

We examined the percentage correct on the landmark recognition task as a way to compare participants' memory of the landmarks situated in both routes. The mean percentage correctly recognized in the total sample was 89% (SD=18%). A trend was found on the landmark recognition task between good and poor SOD, indicating that the good SOD group performed better than the poor SOD group, near significance $F(1,52)=3.807$, $p=.057$. No significant differences among secondary task conditions and their respective control groups where found.

Landmark proximity task

Performance on the landmark proximity task was examined by calculating the total percentage correct on within-route (more egocentric) and between-route (more allocentric) test items. A main effect was found for sense of direction on the two types of routes $F(1,51)=7.296$, $p<.05$. Performance on the within-route task was better than on the between-route task, for both good SOD $t(23)=3.548$, $P<.01$ and poor SOD $t(27)=4.599$, $p<.01$ participants. Contrasts revealed that good SOD participants scored significantly higher on between-route items, but not on within-route items $F(1, 51)=4.164$ compared to the poor SOD participants. $p<.05$ (fig. 3). There was also a significant interaction effect found for sense of direction and secondary task condition on the two types of routes $F(1,51)=2.949$, $p<.05$. Contrasts revealed that there was a significant interaction effect between SOD score and the secondary task condition, but only on the between-route tasks $F(3, 51)=3.674$, $p<.05$. On these tasks, participants in the spatial group scored significantly lower than the control group, but only for good SOD participants ($p<.05$). There was no significant effect for condition or interaction-effect of condition and SOD found on the within-route condition.

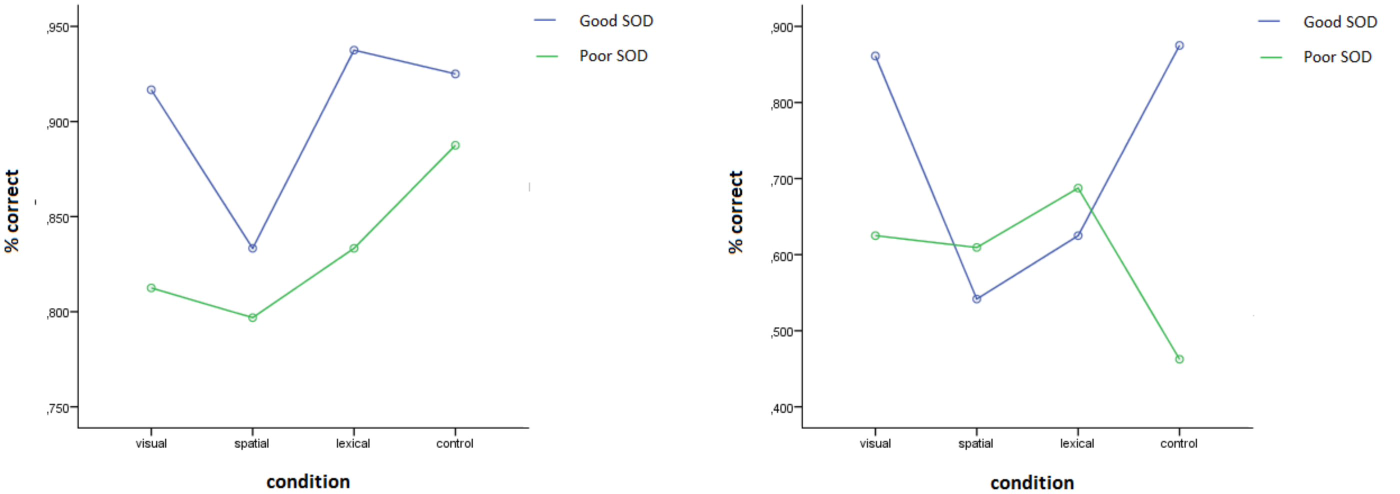

Fig. 3. Differences in accuracy between good and poor SOD participants by condition on within-route (left) and between-route (right) items of the landmark proximity task.

Additionally, performance was better on the within-route proximity task than on the between-route proximity task

Landmark proximity and direction task

For the second landmark proximity task, the accuracy was analyzed for both good and poor SOD participants, not looking at within or between factors. For the direction task, we calculated the pointing error in degrees for each participant on each trial (the difference between the chosen closest landmark, and the direction the participant responded it was in). Then, we calculated the mean for the direction task based on whether they had chosen the correct closest landmark or not. A significant interaction effect of SOD score and secondary task condition was found on the second landmark proximity task $F(3, 51)=6.050$, $p<.05$. Further analysis using contrasts showed that participants with a good SOD in the spatial condition had a significantly lower accuracy than their respective control condition $p<.01$ (fig. 4).

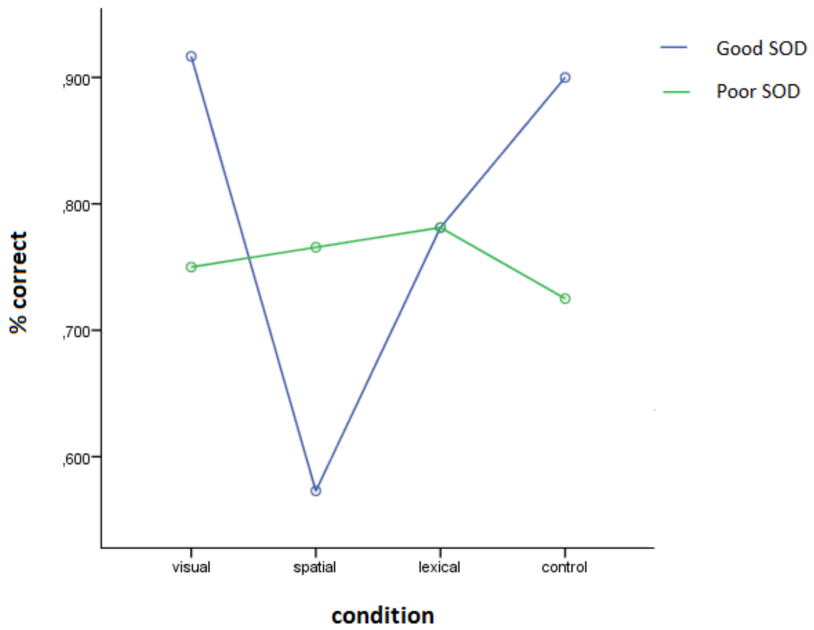

fig. 4. Differences in accuracy between good and poor SOD participants by condition on the second landmark proximity task.

A significant negative correlation was found between the percentage correct on the landmark proximity portion of the task, and the amount of error in the pointing portion of the task if the chosen landmark was correct for good SOD participants r(24)=-.554, p<.01. In other words, if good SOD participants chose the correct landmark more often, they would make less errors when pointing to that landmark.

Landmark drawing task

On the landmark drawing task, good SOD participants scored significantly higher than poor SOD participants F(1, 51)=6.856, p<.05. Performance on the landmark drawing task correlated significantly with the final question added to the SBSOD questionnaire: 'I usually envision a 2D map in mind when learning a new route' r(52)=.30, p<.05. No significant differences among secondary task conditions and their respective control groups where found.

Table 3: Correlations for both aspects of the first landmark proximity task and the landmark drawing task, compared to other measures of this study.
*p<.05. **p<.01

	Landmark recognition task	Landmark drawing task	Second landmark proximity task	Pointing error correct	Map question	SBSOD score
Landmark drawing task	.376**	-	.405**	-.302*	.376**	.393**
Landmark proximity task: between route	.276*	.308*	.613**	-.237	-.031	.306*
Landmark proximity task: within route	.260	.175	.418**	-.288*	.132	.212

Correlations between tasks

Performance on the landmark drawing task, as well as on the within and between-route items of the landmark proximity task were correlated with the other measures of this study (table 3). The landmark drawing task correlated significantly with the landmark recognition task, accuracy on the second landmark proximity task, the amount of pointing error when the chosen landmark was correct on the landmark proximity and direction task, and participants score on the SBSOD questionnaire. Performance on the landmark drawing task also correlated significantly with the final question added to the SBSOD questionnaire: 'I usually envision a 2D map in mind when learning a new route'.

Scores on the between-route items of the first landmark proximity task correlated significantly with performance on the landmark recognition task, the landmark drawing task, accuracy on the second landmark proximity task and participants score on the SBSOD questionnaire.

Scores on the within-route items of the first landmark proximity task correlated significantly with performance on the second landmark proximity task, and the amount of pointing error when the chosen landmark was correct.

Discussion

This study examined how people with a good and poor SOD perform on various egocentric and allocentric survey tasks, and how a two-route method of testing would perform compared to a one-route model of testing. It was also examined if people with different levels of SOD would use different working memory components to obtain survey knowledge.

On the landmark recognition task, good SOD participants assigned more landmarks to the correct routes than participants with a poor SOD. This difference approached significance. Being able to place landmarks in their correct routes showed a significant correlation with performance on the between-route proximity task, and performance on the map drawing task. Both of which are allocentric survey knowledge-type tasks.

In the landmark proximity task, good SOD participants scored higher than poor SOD participants, but only on the between-route items. In the good SOD group, participants in the spatial group scored significantly lower than the control condition. This same effect was found on the second landmark proximity task, where the good SOD visual group scored significantly lower than its control group. On the second proximity and direction task, performance on the distance portion of the task correlated significantly with the direction portion of the task, but only for participants with a good SOD. Finally, the map drawing task significantly correlated with the between-route part of the proximity task, the mental map question, and the second landmark proximity and direction task for good SOD participants.

These findings indicate that people with a good sense of direction perform better than people with a bad sense of direction on any task involving the acquisition and application of route knowledge or survey knowledge, be it from a person-oriented, egocentric perspective, or a more object-to-object related, allocentric perspective. In this study however, the difference between people with a good and poor SOD becomes more apparent when participants had to acquire and apply allocentric survey knowledge in the between-route tasks, rather than the within-route task. Where in previous studies several tasks based on a single route are used to test participant's allocentric survey knowledge, the outcomes of this study show that even though most of these findings are in line with the theoretical framework of Wen and colleagues (2011; 2013) and others (Labate et al. 2014; Ishikawa & Montello, 2006; Meilinger et al. 2008), a two-route form of testing allocentric survey knowledge might be superior. The theory behind this is that a sufficient degree of allocentric survey information is required to perform well on a purely allocentric survey knowledge task. However, in a single-route form of testing, a person who fails to sufficiently acquire the allocentric survey knowledge, could (to some degree) fill in the gaps of information using egocentric-type knowledge, such as egocentric landmark and route knowledge, even when the task is meant to only measure allocentric knowledge (Werner et al, 1997; Meillinger & Vosgerau, 2010). For example, participants could mentally re-walk the route in order to determine the location of several landmarks. By doing this, they use their egocentric route and landmark knowledge to acquire information previously labeled and measured as allocentric survey knowledge. This, in turn, could lead to a smaller performance gap in 'allocentric survey knowledge' tasks to be found, caused by interference of egocentric-type knowledge. The same egocentric-based strategies of information acquisition cannot be used when using a two-route model, partially on the basis that landmarks are not acquired in a uniform direction as they are in one-route forms of testing (Münzer et al., 2006; Montello, 1998). On a between-route task, only allocentric survey knowledge can be used to perform sufficiently, since the two routes and the landmarks within these routes are presented in different angles from one another, egocentric information is insufficient to infer landmark-to-landmark knowledge (Siegel & White, 1975; Montello, 1998; Burgess, 2006). Using a between-route task could result in a larger performance gap becoming apparent between good and poor SOD groups (fig. 5), making this a potentially useful task to include in these types of studies, especially in ones where differences between good and poor SOD groups have not been found consistently, differences aren't very pronounced, or a floor or ceiling effect might interfere with performance.

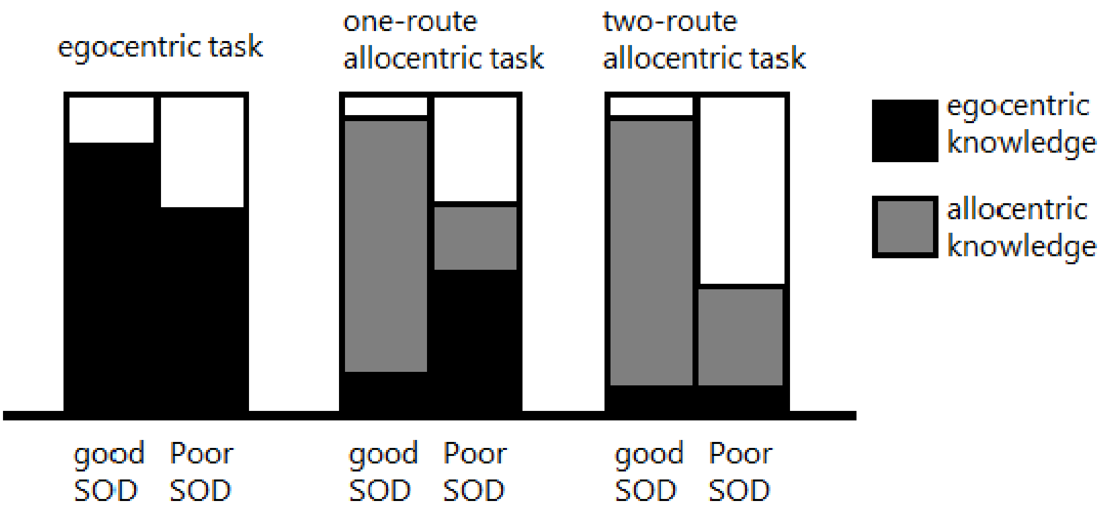

Fig 5. Proposed relative proportion of knowledge used during an egocentric task, one-route allocentric task, and a two-route allocentric task for people with a good and poor SOD.

To further strengthen the position of the two-route mode of testing allocentric survey knowledge, we tested the validity of the method by comparing it to other, typically used forms of testing allocentric knowledge.

First, all tasks that measure some form of allocentric survey knowledge, showed a significant correlation with the between-route mode of testing. The within-route mode of testing, however, only correlated with both aspects of the second landmark proximity and direction task. This task contained both between and within-route items, resulting in a measure of both egocentric and allocentric knowledge.

Second, all tasks that measure allocentric survey knowledge showed a significant difference between good and poor SOD groups. Again, the within-route method of testing showed no significant difference between good and poor SOD groups.

Third, differences in performance across conditions between good and poor SOD groups are in line with similar research (Wen, 2013; Deyzac, Logie, & Denis, 2006), but only on performance for the between-route items. In the good SOD group, performance on the between-route proximity task was significantly worse in the spatial group, and approached significance in the lexical group, as found in the research of Wen and colleagues (2013). While no performance difference was found across conditions for the poor SOD group.

Fourth, the study of Wen and colleagues (2013) found that both good and poor SOD participants performed better on egocentric direction tasks compared to allocentric direction tasks. Wen and colleagues (2013) argue this finding indicates that egocentric relations are easier to understand than allocentric ones, even for people with a good SOD. In this study, performance on the between-route task was worse than on the within-route task, a task normally used to test allocentric knowledge. This finding is in line with our proposed theory of the between-route task being a more allocentric-type measure than a one route, within-type task. If a task requires more allocentric knowledge, that task becomes more difficult. More information has to be acquired, integrated and used in order to perform according to a certain criterion compared to other tasks that require less allocentric knowledge. However, more research is required to investigate the relationship of egocentric, allocentric one-route and allocentric two-route tasks, and the aspects of working memory involved in them. This way these three methods of testing can be compared in difficulty, and more insight can be acquired in the mechanisms involved in its task difficulty.

An interesting finding of this study is a significant correlation between both correct distance and direction estimations for good SOD participants, but not poor SOD participants. This correlation shows that in general, when good SOD participants did well on the distance task, they also did well on the direction task. This correlation was not found for poor SOD participants, meaning that performance on the distance task was not related to performance on the direction task. This could mean that poor SOD participants might vary more in the degree to which they acquire direction and distance information. This result could suggest that poor SOD participants acquire some forms of allocentric survey knowledge, but not enough to perform consistently well on allocentric survey knowledge tasks, where good SOD participants acquire both more consistently. More research is required to gain insight into this possibility, and the possible factors that underlie inconsistencies in poor SOD performance.

Only a few significant differences across allocentric tasks could be found between the several working memory conditions when comparing them to their control conditions. Because of this, the overall findings could not be used to support earlier research to the intended extend. A possible reason for this could be the unequal distribution of good and poor SOD participants among the several conditions. This causes the sample to be unrepresentative between the working memory conditions. Possible solutions to avoid this in future studies, is to first acquire the mean SOD score of participants before testing, or to calculate the SOD score of participants immediately after testing, in order to control an equal distribution among conditions. Secondly, both direction and distance in the second landmark proximity and direction task were tested at the same time. The implication of this is that if participants chose the wrong landmark, they have a higher chance of making a larger pointing error. This entangles the results to the point that a pointing error estimation for good and poor SOD groups for within and between-route tasks could not accurately be attributed to either a distance or pointing error. In future research, the pointing task would be best performed separate, without a distance estimation task, having to point from one landmark to the other, as was done in the research of Maguire and colleagues (1995) and the study of Shinazi and colleagues (2006).

In summary, these findings suggest strong evidence in favor of using a two-route model to study allocentric survey knowledge. The two-route model of testing showed a bigger performance gap between participants with a good and poor SOD, similar to other forms of allocentric knowledge testing. All of these allocentric-type measures also show the same difference between good and poor SOD participants. In addition, a two-route model of testing is more theoretically grounded as requiring more aspects of allocentric survey knowledge in order to perform sufficiently on the task. This leads to the conclusion that a two-route model of testing is a noteworthy asset to studying allocentric survey knowledge in particular. Its true power as a testing tool is yet to be revealed, and should be considered as an addition to research examining the role of working memory in particular. Sometimes all you need is a different point of view.

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