Not all memories are the same: situational context influences spatial recall within ones city of residency

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Abstract

Reference frames in spatial memory encoding have been examined intensively in recent years. However, their importance for recall has received considerably less attention. Passers-by used tags to arrange a configuration map of prominent city-center landmarks. Such configurational knowledge has been shown to be memorized within a north-up reference frame. However, participants adjusted their maps according to their body orientation. For example, when participants faced south, the maps were likely south-up. Participants also constructed maps along their location perspective that is the self-target direction. If, for instance, they were east of the represented area their maps were west-up. If location perspective and body orientation were in opposite directions (i.e., participants faced away from the city center) participants relied on location perspective. Results indicate that reference frames in spatial recall depend on the current situation rather than on memory organization in long-term memory. These results cannot be explained by activation spread within a view-graph which was used to explain similar results on the recall of city plazas. However, results are consistent with forming and transforming a spatial image of non-visible city locations from the current location. Furthermore, prior research almost exclusively focused on body and environment-based reference frames. The strong influence of location perspective in an everyday navigational context indicates that such a reference frame should be considered more often when examining human spatial cognition.

Introduction

When navigating through a familiar environment, navigators access long-term memory about the environment to guide reasoning about it or to plan navigation. While a large quantity of research has focused on how an environment is encoded in memory, especially relative to which reference frame (i.e., coordinate system), the question of its retrieval has been less thoroughly examined. One core assumption is that navigators have to be physically or mentally aligned with the reference frame orientation in their memory to directly access this memory. Otherwise, further processing (e.g., mental rotation) is required to align the memorized reference frame orientation with navigators' current orientation, yielding an increase in errors and/or latency (McNamara, Sluzenski, & Rump, 2008). This assumption allows measuring reference frame orientation in memory by identifying the body orientation(s) yielding best spatial performance.

However, not only misalignment influences spatial memory retrieval and performance in spatial tasks. When navigators are mentally or physically localized within a familiar room, their reasoning will also be influenced by their current position and orientation within this room. For example, a navigator physically facing the door and being asked to make spatial judgments while imagining facing the window, will show a decrease in performance in addition to a memory-alignment effect (Avraamides & Kelly, 2010; Kelly, Avraamides, & Loomis, 2007). This effect presumably arises from interference between the perception (and internal representation) of one's current position and the imagined, tested position (May, 1996). Such interference might also occur between one's currently visible environment (i.e., wall geometry) and the orientation this environment was memorized in long-term memory (Meilinger & Bülthoff, 2013). One interpretation of these studies is that the ongoing perceptual input interferes with a working memory representation or a spatial image (Loomis, Klatzky, & Giudice, 2013) of the target environment. Other findings also support the idea of a spatial image in working memory. Giudice, Klatzky, Bennett, and Loomis (2013) showed that spatial working memory content (i.e., locations within a room) accessed from perception or from long-term memory only sometimes differ in precision and are easily combined. Visual and haptic perception form equivalent spatial images which can be updated through movement (Guidice, Betty, & Loomis, 2011). Spatial images are not limited to the immediate visible surrounding, but may encompass remote spaces as well. Such remote spaces might be added from long-term memory during navigation (Wang & Brockmole, 2003). Adding all spaces along a route to a target might be a strategy to derive survey relations from navigation-acquired knowledge (Meilinger, 2008). An advantage for imagining remote spaces (i.e., beyond the border of the currently visible space) is that there is no conflict between the current visible space and the remote space, as they represent different areas and not the same area twice. Indeed, interference only occurs when imagining standing in a different body orientation inside ones current room, not when imagining standing inside an adjacent room (Avraamides & Kelly, 2010; Kelly et al., 2007).

Building a spatial image of a remote location may be useful for spatial reasoning. This image can be influenced by the current situation (i.e., one's location in an environment) as shown by Röhrich, Hardiess, and Mallot (2014): Pedestrians drew sketch maps of well-known near-by city plazas. Resulting maps were often oriented along the perspective participants had viewed the plaza (e.g., west-up when located east of the plaza), although the plaza was a few streets away and never visible. This location effect was only present nearby the target. Participants drew maps at remote locations in the same default orientations no matter where they made the sketch. However, if participants were asked to imagine walking a route that involved crossing the particular plaza, then a situational influence could be induced also at a distant location (Basten, Meilinger, & Mallot, 2012): Participants more often drew the map in an imagined walking orientation (e.g., west-up when imagining walking east to west) and less often in the default orientation. These studies showed that physical and imagined locations influence the reference frame within which a plaza was recalled.

In terms of a spatial image, two underlying mechanisms seem plausible for the described results: pre-activation or mental rotation. For pre-activation, participants stored multiple views of a plaza within long-term memory. By imagining walking a certain route, matching views are activated, thus priming recall, and leading to a map drawing oriented along the previously imagined viewing direction. For recalling near-by locations, view pre-activation is transferred through a view graph (Röhrich et al., 2014). In view graphs, views along travelled routes are interconnected and activation spreads along these connections (cf., Schweizer, Herrmann, Janzen, & Katz, 1998). Activation from participants' current locations spreads along views of a route leading to the target plaza and pre-activates the view encountered when entering the plaza. Location in different cardinal direction around a plaza will activate different routes and connected plaza views changing the preferred recall during later map drawing. Routes from far remote locations are too long or noisy to spread activation, therefore, the default view is recalled.

Alternatively, plaza layout of an area is represented within one integrated representation and recalled within the underlying reference frame by default. Recall from nearby locations involves imagining the plaza – as well as routes leading there - from the perspective of a navigator's current location, and its rotation from the default orientation into this location perspective (cf. Meilinger, 2008 for details of such a process). Recall from remote locations would involve too many locations to be included into the spatial image within working memory (i.e., all streets leading to the target). Therefore, default orientations are used.

Activation spread and mental rotation can both explain situational adjustments in recalling city plazas. The first motivation for the present study was to test whether adjustment is also observed in a situation never explored before where only one mechanism, mental rotation, is applicable: Recalling configurational or survey knowledge (i.e., the spatial relations between mutually non-visible locations). This knowledge is represented within a single north-up oriented reference frame (Frankenstein, Mohler Bülthoff, & Meilinger, 2012) – explicitly for Tübingen where the current study was conducted. Participants might mentally rotate recalled city configurations to adjust to the current location. However, as this knowledge is NOT organized along a view graph, activation spread is not possible. If participants recall configuration from their current location this must be based on mental rotation. Testing a novel situation gave us the opportunity to probe the underlying mechanism of adjustment.

The second, independent motivation for the study concerned the reference frame within which knowledge was retrieved, namely body-based or location perspective. Both reference frames are not identical, as indicated in a study by Waller, Lippa, and Richardson (2008). In this study, participants memorized an object layout placed left of where their body, head and eye was facing. Recall from different imagined orientations showed that participants encoded this layout relative to the self-to-target line or location perspective rather than relative to their body-, head-, or eye-orientation. Therefore, location perspective can dominate body-based reference frames within memory for an object layout. For learning a layout, both orientations cannot differ too much as the layout must still be visible. This is different when recalling spatial information within an overlearned, navigable environment. For example, when located west of a target area and facing west, recall along one’s orientation will yield a west-up reference frame. However, recall along the location perspective will yield an east-up reference frame as the perspective from west onto the target area is eastwards. In the study by Röhrich et al. (2014), participants recalled the plaza from their current location perspective. However, as participants could turn around and align their body orientation with the location perspective, is not clear whether location perspective or body-front perspective defined the reference frame of recall. By testing recall at different locations around a target area with people in different body orientations, including an offset between body orientation and location perspective, this is the first study to estimate which reference frame is relevant for recall in an everyday environment. In addition to body orientation and location perspective, we also tested whether participants recalled configurational knowledge north-up as this was the reference frame orientation in which this knowledge was memorized within long-term memory (Frankenstein et al., 2012). Last, we also examined whether the home perspective, that is the perspective onto the target area from a participants home (e.g., south when living north of the target area) influenced spatial memory recall, as it is the most often experienced perspective of participants onto the target area. In summary, we asked if participants adjusted spatial recall to their current situation as an indicator for the underlying process (view spread vs. mental rotation) and reference frame (body based, north-up, location and home perspective).

Methods

We asked passers-by already sitting at tables in pubs and cafes to report knowledge about the configuration of prominent landmarks within their city of residency. They recalled the spatial configuration of ten prominent landmarks within the city center by arranging named tags on a sheet of paper (Figure 1).

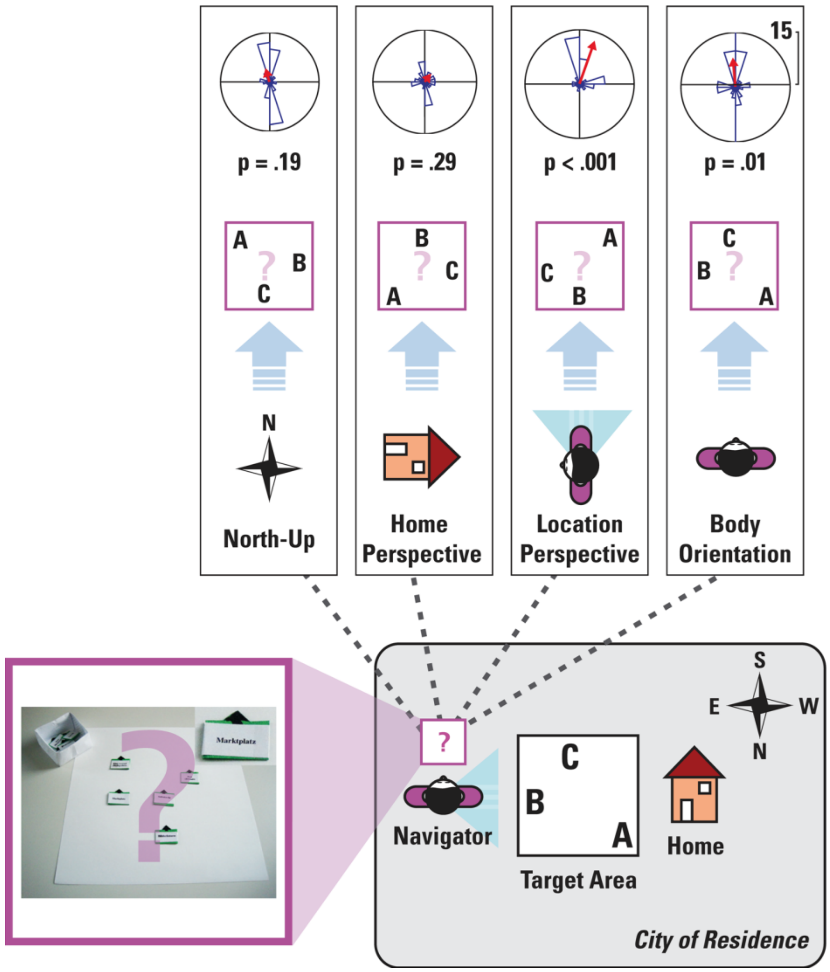

Figure 1. Experimental procedure and results. Participants were asked to pick up tags from a box naming popular locations within the city center of Tübingen and arrange them in the correct configuration (bottom left). These maps might be assembled in different orientations. For example, a navigator is asked to recall target locations (here A, B and C) of a close-by target area while being located east of the target area facing south. If simply accessing map-based knowledge, the map will be arranged north-up. A map built from the navigator's current body orientation will be south-up. It will be west-up if assembled from the perspective of the navigator's current location onto the target area (the view when turning right). Finally, the map will be oriented east-up if arranged from the perspective of the navigator's home. At the top circular histograms show the obtained map orientations relative to these four orientations. P-values < .05 indicate clustering around the predicted orientation. Arrows show the circular (i.e., vector) average of all map orientations.

Participants

60 Tübingen residents agreed to participate (34 male; age: [18, 57]; $M = 30$; $SD = 9.7$; years in Tübingen: [0.3, 46]; $M = 10.5$; $SD = 10.1$; distance home - city center < 10km). Participants were not rewarded monetarily, gave informed consent, and were free to stop the experiment any time without giving a reason. This research was approved by the ethical committee of the University Clinic Tübingen.

Material and procedure

We tested participants' configurational knowledge between ten familiar locations situated within the city center of Tübingen, for example the castle, the town hall, the cathedral, the firefighter building, etc. Figure 2 displays this configuration in a north-up orientation. To express this configuration, participants arranged ten named tags on a 30x30cm sheet of paper (see Figure 1). Short explanations of the locations were provided on the back of the tags and participants were encouraged to ask the experimenter in case they did not recognize a location. Participants picked the tags from a box in random order, and were free to rearrange them until being satisfied with their solution. No emphasis on speed was given. Participants were allowed to turn their head (e.g., to look towards the city center, although it was always occluded), but remained seated during the experiment. Before removing the tags, the experimenter copied the tag locations on the paper. Participants then filled a questionnaire assessing demographic data, the part of the city participants live in, time spent in Tübingen, participants' experience with maps and their self-estimated sense of direction. Last, not visible to any participant, north was determined using a compass and marked on the maps.

To test the influence of body orientation, participants already seated in the appropriate orientation (i.e., north, east, south or west) were asked to participate. We varied the location perspective by collecting data in five pubs/cafes located north, west, south, east and within the target area (see the origins of the circular histograms in Figure 2 – 12 participants at each location). While body orientation and location perspective were counterbalanced, home perspective could not be counterbalanced. A chi-square test of independence revealed that home perspective was not related to body orientation (X^2 (1, $N = 57$) = .47, $p = .491$), but to location perspective (X^2 (1, $N = 57$) = 8.90, $p < .01$).

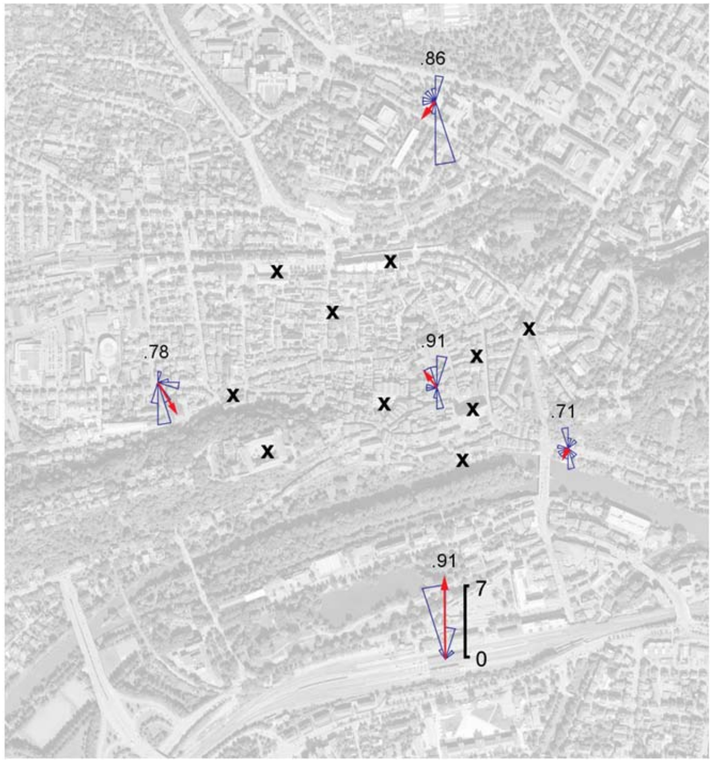

Figure 2: Target locations within the city center of Tübingen (X's) and test locations (origin of circular histograms). The histograms show the frequency of map orientations at a test location irrespective of body orientation. Participants' maps were orientated along participants' body orientation, when located east of (p = .001) and within the target area (p = .046). Clustering around the location perspective was observed at test locations west (p = .049) and south (p < .001). The numbers above the histograms indicate map quality in terms of common variance (R^2) of the produced layout with the correct layout. The picture was adopted from Google maps.

The locations of the tags on the maps were transformed into 2D-coordinates and related to correct coordinates using bi-dimensional regression (Friedman & Kohler, 2003). Bi-dimensional regression estimates the similarity between two maps in terms of common variance (R^2) after correcting for scaling and rotational offset (i.e., different orientations). Map orientations were plotted relative to predicted orientations (i.e., north, body orientation, location and home perspective onto the city center). Significant v-tests (Zar, 2010) indicated that map orientations clustered around the one tested orientation rather than around a different orientation or being homogeneous.

We also examined map quality (i.e., R^2) as a function of body-orientation, location and home perspective relative to north and body-orientation relative to location and home perspective. Finally, we compared map quality as a function of how much the map orientation itself deviated from north, body orientation, location perspective or home perspective. However, this last analysis did not reveal any significant differences, but only small numerical advantages for maps oriented north or along the location perspective and is thus not reported.

Results

The first question asked within this study was whether participants adjusted their configurational knowledge according to their current location and body orientation during recall. Figure 1 shows the frequency of map orientations relative to north, home perspective, location perspective, and body orientation. Participants aligned their maps with their location perspective and body orientation, but not with directions defined by north or home. This indicates that situational adjustment is also possible with configurational knowledge.

The second motivation for the study was to examine the relative influence of body orientation and location perspective. Figure 3 shows map orientations when body orientation and location perspective were aligned, orthogonal, or contra-aligned. When aligned, participants produced maps along this direction. For orthogonal misalignments, the bi-modal distribution suggests that both reference frames mattered, and more so body orientation than location perspective as location perspective did not reach significance in the uni-modal tests (i.e., testing whether the whole distribution is clustered around body orientation or location perspective). In case of contra-alignment, participants clearly used the location perspective and not body orientation. These results suggest that body orientation mainly played a role, if there was no large conflict with location perspective.

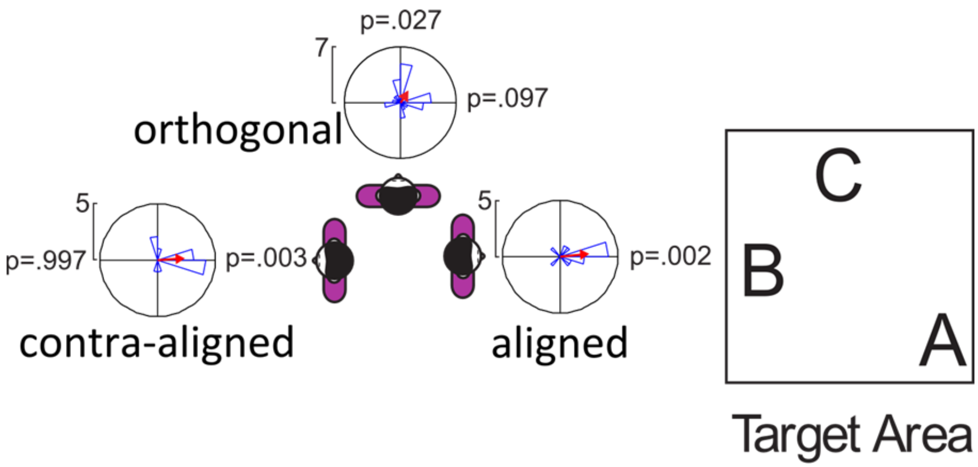

Figure 3: Frequency of map orientations when body-orientation and location perspective were aligned, orthogonal, or contra-aligned. Location perspective is here to the right towards the target area. P-values displayed on the right side of the histograms indicate clustering around location perspective. P-values on the side opposite to the body indicate clustering along body orientation. We aggregated map orientations over the four test locations around the target area and across both orthogonal misalignments.

In general, bi-dimensional regression revealed an average correlation between produced maps and real spatial configuration of $R^2 = .84$ ([.36 to .98], $SD = .15$). However, test location influenced map quality, $F(4,55) = 4.59$, $p = .003$, $\eta_p^2 = .25$ (see Figure 2). When no location perspective was present (i.e., within the city center) and when the location perspective was north-up (i.e., southward test location), participants produced better maps compared to test locations east or west of the city center (t's > 2.19, p's < .047, $d' > 0.89$, additionally location north was better than east, $t(22) = 2.16$, $p = .042$, $d' = 0.88$). Body orientation relative to north, location or home perspective, or home perspective relative to north did not influence map quality, $F < 1$.

Discussion

Participants recalled configurational information within reference frames based on body orientation and on location perspective (i.e., self-to-target line). In spatial cognition research these reference frames are typically not differentiated and only body-based frames are considered. However, in accordance with Waller et al. (2008), our results show that both reference frames are indeed relevant, and by analyzing conflicting situations (i.e., contra-alignment), we found location perspective dominant. While Waller et al. (2008) showed this for location memory in a laboratory setup, the present work extends these findings to spatial recall in navigable environments, suggesting this differentiation is indeed a relevant aspect of everyday navigation.

The adjustment of spatial information according to the test location replicates findings from the recall of the layout of plazas (Basten et al., 2012; Röhrich et al., 2014) with different material, namely the configuration of locations. Röhrich et al. (2014) explained their results by activation spreading along a route from the test location pre-activating the first view encountered at the target plaza. This explanation by view pre-activation cannot hold for the present experiment. Configurational knowledge – specifically within Tübingen - is represented within a single north-up reference frame (Frankenstein et al., 2012), not within a graph structure (Meilinger, Frankenstein, & Bülthoff, 2013) suited for activation spread. Furthermore, activation spread would predict no influence of body orientation which we, however, observed. In extension to previous work we conclude that situational adjustment of spatial long-term memory does not require pre-activation.

An alternative process affirms that navigators constructed a spatial image of their non-visible surrounding within their working memory, by accessing their single-reference frame long-term memory and mentally rotating it into the orientation defined from their current location and body orientation.

The current work adds to the growing number of spatial tasks evidencing involvement of a spatial image (Avraamides & Kelly, 2010; Giudice et al., 2011; 2013; Kelly et al., 2007; May, 1996; Wang & Brockmole, 2003). In extension to previous work the current tasks involves mental rotation rather than updating during bodily movement (Guidice et al., 2011) and incorporates configurations within a city rather than locations in the immediate surrounding (Avraamides & Kelly, 2010; Giudice et al., 2011; 2013; Kelly et al., 2007; May, 1996; Wang & Brockmole, 2003).

Why did participants align their configurational knowledge to their current location and orientation within the city at all? This alignment is surprising as alignments involve costs (Meilinger, Berthoz, & Wiener, 2011) that participants could have avoided by simply recalling configurations in the north-up frame, knowledge of which is encoded in long-term memory (Frankenstein et al., 2012). Maybe the alignment served to have locations ready for future acting. A spatial image of the non-visible environment anchors the recalled locations in the environment relative to navigators which enables the navigators to directly approach such locations or to estimate their distance and direction (e.g., pointing). Please note that no mental rotation was required for recall along the location perspective when participants' location perspective was north-up. Also, these maps were, first, preferably recalled along the location perspective, and second, more accurate than maps using most other location perspectives.

In the present study, we did not test the default recall orientation as in prior work on plaza recall (Basten et al., 2012; Röhrich et al., 2014). However, as pointed out in the supplementary material, un-reported data from another experiment (Frankenstein et al., 2012) suggests, first, that location perspective recall of configurations is observed also in a map drawing task and that it is also observed at a somewhat remote location (the distance test location – city center was similar to another study which observed default recall - Basten et al., 2012). This makes sense as the plaza layout was likely learned from local navigational experience. However, configurational knowledge was rather learned from a map, which typically involves the whole city and where the area of influence should be larger. We also did not observe default orientation within the city center when no location perspective was present. Here participants recalled locations along their body orientation.

Is location perspective egocentric or allocentric? From our point of view this is a question of definition. If egocentric is defined as changing with movement (Röhrich et al., 2014) location perspective is egocentric as it changes its' orientation when navigators move around. In this conception all long-term memory is allocentric. If egocentric is defined as centered on a body part (e.g., torso, head, eye) and oriented along the forward orientation of this part (Klatzky, 1998) then location perspective is not egocentric as the location perspective onto the city center does not change when rotating around ones axes, but city locations in body-based frames do. However, location perspective might not be allocentric either as allocentric reference frames obtain their origin and orientation from the environment alone, but location perspective depends on the location of a navigator.

Perhaps the dominant egocentric-allocentric divide is too coarse, and terminology will not be a central issue as long as the involved reference frames are clearly specified.

Conclusion

Prior research on spatial memory largely focused on encoding. Our results show that reference frames encoded in long-term-memory are not necessarily those within which spatial information is recalled; navigators adjust information to their current situation, that is location and body orientation. The pattern of adjustment cannot be explained by activation spread along graph-representations, but is consistent with forming and transforming a spatial image of non-visible spatial locations within working memory. Furthermore, prior research focused almost exclusively on body- and environment-based reference frames. The strong influence of location perspective in an everyday navigational context indicates that such a reference frame should also be considered more often when examining human spatial cognition.

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