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BRIEF REPORT

Not all memories are the same: Situational context influences spatial recall within one's 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. In the present study, passersby used tags to arrange a configuration map of prominent city center landmarks. It has been shown that such configurational knowledge is memorized within a north-up reference frame. However, participants adjusted their maps according to their body orientations. For example, when participants faced south, the maps were likely to face 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 oriented west-up. If the location perspective and body orientation were in opposite directions (i.e., if participants faced away from the city center), participants relied on location perspective. The results indicate that reference frames in spatial recall depend on the current situation rather than on the organization in long-term memory. These results cannot be explained by activation spread within a view graph, which had been used to explain similar results in the recall of city plazas. However, the results are consistent with forming and transforming a spatial image of nonvisible city locations from the current location. Furthermore, prior research has 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.

Keywords Navigation · Spatial memory · Recall · Embodied cognition · Working memory

When navigating through a familiar environment, navigators access long-term memory about the environment to guide reasoning about it or to plan navigation. Although 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 retrieving this memory 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) would be required to align the memorized reference frame orientation with navigators' current orientation, yielding an increase in errors and/or latencies (McNamara, Sluzenski, & Rump, 2008). This assumption allows measuring reference frame orientation in memory by

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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 of this environment that is 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's contents (i.e., locations within a room) only sometimes differ in precision when accessed from perception or from long-term memory, and these representations are easily combined. Visual and haptic perception form equivalent spatial images that can be updated through movement (Giudice, Betty, & Loomis, 2011). Spatial images are not limited to the immediate visible surroundings, 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, since they represent different areas and not the same area twice. Indeed, interference only occurs when imagining standing in a different body orientation inside one's 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 was shown by Röhrich, Hardiess, and Mallot (2014): Pedestrians drew sketch maps of well-known nearby city plazas. The resulting maps were often oriented along the perspective from which participants had viewed the plaza (e.g., west-up when they were located east of the plaza), although the plaza was a few streets away and never visible. This location effect was only present for a 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 also be induced at a distant location (Basten, Meilinger, & Mallot, 2012): Participants more often drew the map in an imagined walking orientation (e.g., west-up when they imagined walking from 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: preactivation or mental rotation. For preactivation, participants store 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 nearby locations, view preactivation 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 (Schweizer, Herrmann, Janzen, & Katz, 1998). Activation from participants' current locations spreads along views of a route leading to the target plaza and preactivates the view encountered when entering the plaza. Location in different cardinal directions 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, the plaza layout of an area may be 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 (see 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 would also be observed in a situation never explored before, in which only one mechanism, mental rotation, would be applicable: recalling configurational or survey knowledge (i.e., the spatial relations between mutually nonvisible locations). This knowledge is represented within a single, north-up-oriented reference frame (Frankenstein, Mohler, Bülthoff, & Meilinger, 2012)—explicitly for Tübingen, where the present study was conducted. Participants might mentally rotate recalled city configurations to adjust to the current location.

However, because this knowledge is *not* organized along a view graph, activation spread is not possible. If participants recall configurations 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 has been indicated in a study by Waller, Lippa, and Richardson (2008). In their study, participants memorized an object layout placed left of where their body, head, and eye were 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, since 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 would yield a west-up reference frame. However, recall along the location perspective would yield an east-up reference frame, since the perspective from west onto the target area is eastward. In the study by Röhrich et al. (2014), participants recalled a plaza from their current location perspective. However, because participants could turn around and align their body orientation with the location perspective, it is not clear whether location perspective or body-front 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, ours was 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, since this was the reference frame orientation in which this knowledge was memorized within long-term memory (Frankenstein et al., 2012). Finally, we also examined whether the home perspective—that is, the perspective onto the target area from a participant's home (e.g., south when living north of the target area)—influenced spatial memory recall, since this would be the perspective onto the target area most often experienced by participants. In summary, we asked whether participants adjusted spatial recall to their current situation as an indicator for the underlying process (activation spread vs. mental rotation) and reference frame (body-based, north-up, or location or home perspective).

Method

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

Participants

A total of 60 Tübingen residents agreed to participate (34 male, 26 female; age: [18, 57], M = 30, SD = 9.7; years in Tübingen: [0.3, 46], M = 10.5, SD = 10.1; distance from home to city center < 10 km). Participants were not rewarded monetarily, gave informed consent, and were free to stop the

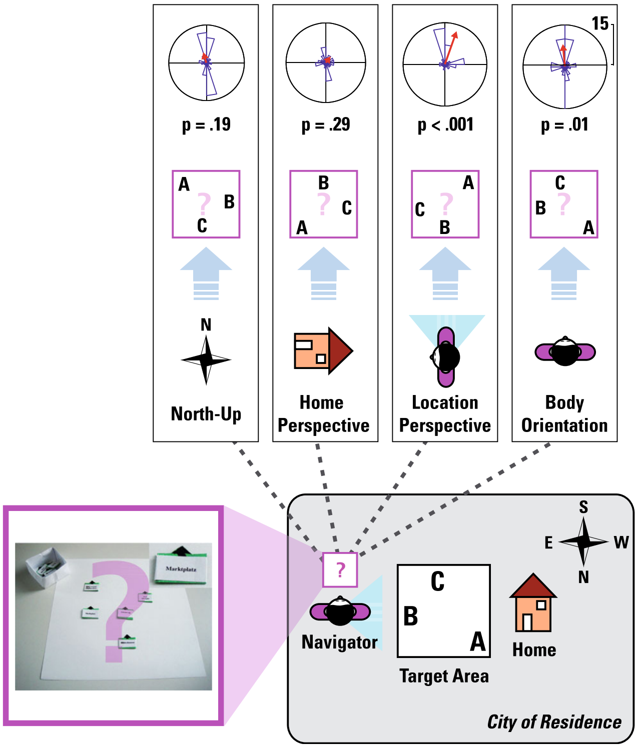

Fig. 1 Experimental procedure and results. Participants were asked to pick up tags from a box naming popular locations within the city center of Tübingen and arrange them in the correct configuration (bottom left). These maps might be assembled in different orientations. For example, a navigator might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

experiment at any time without giving a reason. This research was approved by the ethics committee of 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, town hall, cathedral, firefighter building, and so forth. Figure 2 displays this configuration in a north-up orientation. To express this configuration, participants arranged ten named tags on a 30 × 30 cm sheet of paper (see Fig. 1). Short explanations of the locations were provided on the backs 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 they were satisfied with their solution. No emphasis on speed was given. Participants were allowed to turn their head (e.g., to look toward the city center, although it was always occluded), but they remained seated during the experiment. Before removing the tags, the experimenter copied the tag locations onto the paper. Participants then filled out a questionnaire assessing demographic data, the parts of the city participants lived in, time spent in Tübingen, participants' experience with maps, and their self-estimated sense of direction. Finally, not visible to any participant, north was determined by using a compass and was marked on the maps.

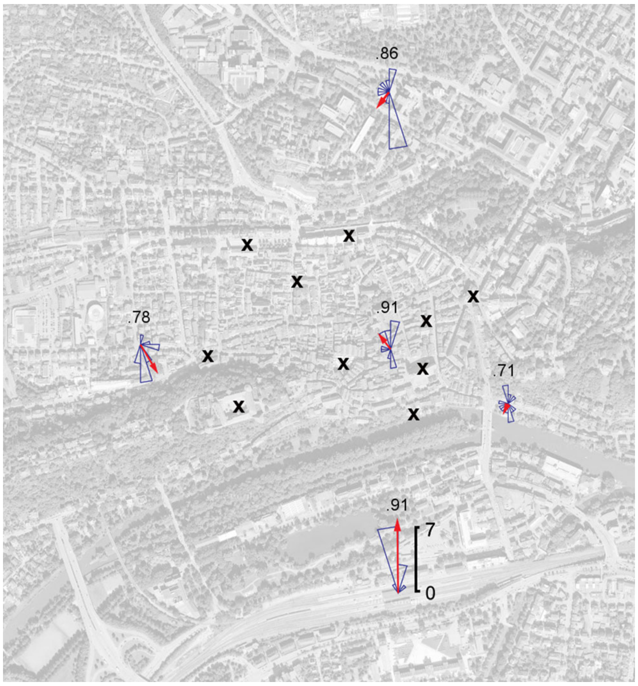

Fig. 2 Target locations within the city center of Tübingen (Xs) and test locations (origins of circular histograms). The histograms show the frequencies of map orientations at a test location, irrespective of body orientation. Participants' maps were oriented along their body orientation when participants were located east of (p = .001) and within (p = .046) the target area. 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 the common variance (R^2) of the produced layouts with the correct layout. The picture was taken from Google 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, and east of, as well as within, the target area (see the origins of the circular histograms in Fig. 2: 12 participants at each location). Body orientation and location perspective were counterbalanced, but home perspective could not be counterbalanced. A chi-square test of independence revealed that home perspective was not related to body orientation [$\chi^2(1, N = 57) = 0.47, p = .491$], but was related to location perspective [$\chi^2(1, N = 57) = 8.90, p < .01$].

The locations of the tags on the maps were transformed into 2-D coordinates and related to the correct coordinates by using bidimensional regression (Friedman & Kohler, 2003). Bidimensional 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 the predicted orientations (i.e., north, body orientation, location, and home perspectives onto the city center). Significant v tests (Zar, 2010) indicated that the 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, as well as 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 the north, body orientation, location, 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 thus is 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 frequencies 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 the 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 influences of body orientation and location perspective. Figure 3 shows map orientations when the body orientation and location perspective were aligned, orthogonal, or contra-aligned. When they were aligned, participants produced maps along this direction. For orthogonal misalignments, the bimodal distribution suggests that both reference frames mattered, and body orientation mattered more than location perspective, because location perspective did not reach significance in the unimodal tests (i.e., testing whether the whole distribution was clustered around body orientation or location perspective). In the 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.

In general, a bidimensional regression revealed an average correlation between the produced maps and the real spatial configuration of R^2 = .84 ([.36 to .98], *SD* = .15). However, test location influenced map quality, $F(4, 55) = 4.59$, $p = .003$, η_p^2 = .25 (see Fig. 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 than in the test locations east or west of the city center [*t*s > 2.19, *p*s < .047, $d' > 0.89$; additionally, performance was better at the north than at the east location, $t(22) = 2.16$, $p = .042$, $d' = 0.88$]. Body orientation relative to north; location or home perspective; and home perspective relative to north did not influence map quality, *F*s < 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 showed that both reference frames are indeed relevant, and by analyzing conflicting situations (i.e., contra-alignment), we found the location perspective to be dominant. Although 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 that this differentiation is indeed a relevant aspect of everyday navigation.

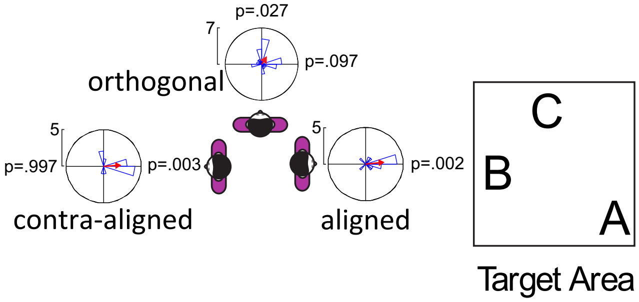

Fig. 3 Frequency of map orientations when body orientation and location perspective were aligned, orthogonal, or contra-aligned. The location perspective is here to the right, toward the target area. The *p* values displayed on the right sides of the histograms indicate clustering around the location perspective; the *p* values on the sides opposite the bodies indicate clustering along body orientation. We aggregated map orientations over the four test locations around the target area and across both orthogonal misalignments

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. explained their results in terms of activation spreading along a route from the test location preactivating the first view encountered at the target plaza. This explanation by view preactivation 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 an extension of previous work, we concluded that situational adjustment of spatial long-term memory does not require preactivation.

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

The present work adds to the growing number of spatial tasks evidencing the involvement of a spatial image (Avraamides & Kelly, 2010; Giudice et al., 2011; Giudice et al., 2013; Kelly et al., 2007; May, 1996; Wang & Brockmole, 2003). In the present extension of previous work, the task involved mental rotation rather than updating during bodily movement (Giudice et al., 2011) and incorporated configurations within a city rather than locations in the immediate surroundings (Avraamides & Kelly, 2010; Giudice et al., 2011; Giudice et al., 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, since 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 nonvisible environment anchors 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., by 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, first, were preferably recalled along the location perspective, and second, were 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 we point out in the supplementary material, unreported data from another experiment (Frankenstein et al., 2012) suggest, first, that location perspective recall of configurations is also observed in a map-drawing task and at a somewhat remote location (the distance test location—city center—was similar to that in another study that had observed default recall: Basten et al., 2012). This makes sense, since the plaza layout was likely learned from local navigational experience. However, configurational knowledge is learned instead from a map, which typically involves the whole city, 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 instead along their body orientation.

Is the 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), the location perspective is egocentric, since 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., the torso, head, or eye) and oriented along the forward orientation of this part (Klatzky, 1998), then the location perspective is not egocentric, since the location perspective onto the city center does not change when rotating around one's axes, but city locations in body-based frames do. However, the location perspective might not be allocentric, either, since 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 has 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; instead, navigators adjust information to their current situation—that is, to 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 nonvisible spatial locations within working memory. Furthermore, prior research has 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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References

Avraamides, M. N., & Kelly, J. W. (2010). Multiple systems of spatial memory: Evidence from described scenes. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 36,* 635–645. doi: 10.1037/a0017040

Basten, K., Meilinger, T., & Mallot, H. (2012). Mental travel primes place orientation in spatial recall. In C. Stachniss, K. Schill, & D. Uttal (Eds.), *Spatial cognition VIII* (pp. 378–385). Berlin, Germany: Springer.

Frankenstein, J., Mohler, B. J., Bülthoff, H. H., & Meilinger, T. (2012). Is the map in our head oriented north? *Psychological Science, 23,* 120–125. doi:10.1177/0956797611429467

Friedman, A., & Kohler, B. (2003). Bidimensional regression: Assessing the configurational similarity and accuracy of cognitive maps and other two-dimensional data sets. *Psychological Methods, 8,* 468–491. doi:10.1037/1082-989X.8.4.468

Giudice, N. A., Betty, M. R., & Loomis, J. M. (2011). Functional equivalence of spatial images from touch and vision: Evidence from spatial updating in blind and sighted individuals. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 37,* 621–634. doi:10.1037/a0022331

Giudice, N. A., Klatzky, R. L., Bennett, C. R., & Loomis, J. M. (2013). Combining locations from working memory and long-term memory into a common spatial image. *Spatial Cognition and Computation, 13,* 103–128.

Kelly, J. W., Avraamides, M. N., & Loomis, J. M. (2007). Sensorimotor alignment effects in the learning environment and in novel environments. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 33,* 1092–1107. doi:10.1037/0278-7393.33.6.1092

Klatzky, R. L. (1998). Allocentric and egocentric spatial representations definitions, distinctions, and interconnections. In C. Freksa, C. Habel, & K. F. Wender (Eds.), *Spatial cognition* (pp. 1–17). Berlin, Germany: Springer.

Loomis, J. M., Klatzky, R. L., & Giudice, N. A. (2013). Representing 3D space in working memory: Spatial images from vision, hearing, touch, and language. In S. Lacey & R. Lawson (Eds.), *Multisensory imagery* (pp. 131–155). Berlin, Germany: Springer.

May, M. (1996). Cognitive and embodied modes of spatial imagery. *Psychologische Beiträge, 38,* 418–434.

McNamara, T. P., Sluzenski, J., & Rump, B. (2008). Human spatial memory and navigation. In J. Byrne & H. L. Roediger III (Eds.), *Learning and memory: A comprehensive reference. Vol. 2: Cognitive psychology of memory* (pp. 157–178). Amsterdam, The Netherlands: Elsevier.

Meilinger, T. (2008). The network of reference frames theory: A synthesis of graphs and cognitive maps. In C. Freksa, N. S. Newcombe, P.

Gärdenfors, & S. Wölfl (Eds.), *Spatial cognition VI* (pp. 344–360). Berlin, Germany: Springer.

Meilinger, T., Berthoz, A., & Wiener, J. M. (2011). The integration of spatial information across different viewpoints. *Memory & Cognition, 39,* 1042–1054. doi:10.3758/s13421-011-0088-x

Meilinger, T., & Bülthoff, H. H. (2013). Verbal shadowing and visual interference in spatial memory. *PLoS ONE, 8*, e74177. doi:10.1371/journal.pone.0074177

Meilinger, T., Frankenstein, J., & Bülthoff, H. H. (2013). Learning to navigate: Experience versus maps. *Cognition, 129,* 24–30. doi:10.1016/j.cognition.2013.05.013

Röhrich, W. G., Hardiess, G., & Mallot, H. A. (2014). View-based organization and interplay of spatial working and long-term memories. *PLoS ONE, 9*, e112793. doi:10.1371/journal.pone.0112793

Schweizer, K., Herrmann, T., Janzen, G., & Katz, S. (1998). The route direction effect and its constraints. In C. Freksa, C. Habel, & K. F. Wender (Eds.), *Spatial cognition* (pp. 19–38). Berlin, Germany: Springer.

Waller, D., Lippa, Y., & Richardson, A. (2008). Isolating observer-based reference directions in human spatial memory: Head, body, and the self-to-array axis. *Cognition, 106,* 157–183. doi:10.1016/j.cognition.2007.01.002

Wang, R. F., & Brockmole, J. R. (2003). Human navigation in nested environments. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 29,* 398–404. doi:10.1037/0278-7393.29.3.398

Zar, J. H. (2010). *Biostatistical analysis*. Upper Saddle River, NJ: Prentice Hall.