The planar mosaic fails to account for spatially directed action

doi:10.1017/S0140525X13000435

Roberta L. Klatzky[a] and Nicholas A. Giudice[b]

[a]Department of Psychology, Carnegie Mellon University, Pittsburgh, PA15213; [b]Spatial Informatics Program, School of Computing and Information Science, University of Maine, Orono, ME 04469-5711.

klatzky@cmu.edu nicholas.giudice@maine.edu
http://www.psy.cmu.edu/people/klatzky.html
http://spatial.umaine.edu/faculty/giudice/

Abstract: Humans' spatial representations enable navigation and reaching to targets above the ground plane, even without direct perceptual support. Such abilities are inconsistent with an impoverished representation of the third dimension. Features that differentiate humans from most terrestrial animals, including raised eye height and arms dedicated to manipulation rather than locomotion, have led to robust metric representations of volumetric space.

Consider some human capabilities for actions directed at spatial targets at varying distances above the ground plane: at an extreme, snagging a fly ball on the run or pole vaulting; at the mundane level, turning on the wall switch or stepping over an obstacle on the ground. These actions are accurate and precise; yet they generally are not performed under closed-loop control that would free us from metric demands. It seems unlikely that the planar mosaic representation proposed by Jeffery et al. – where the third dimension is not only non-metric, but unstable – could support their execution.

How do we resolve the disparity between what would be possible under a non-metric representation of space and what people can actually do? One avenue toward resolution is to say, "Oh, but Jeffery et al. are not referring to those types of behaviors." But what, then, differentiates the behaviors ostensibly governed by the planar mosaic from human spatially directed actions such as pointing, reaching, over-stepping, and making contact?

For one thing, actions such as catching balls and reaching for targets on a wall result from characteristics of human perception and action that most other terrestrial mammals do not share. Humans are "ecologically three-dimensional" to a high degree. Our raised eyes provide a perspective view of the terrain where we might travel, within a volumetric context so vast it has been called "vista space" (Cutting & Vishton 1995). Although not without error, our representation of height variation across environmental undulations is simply not possible for animals whose sense organs remain close to the ground during navigation. Humans differ as well from rodents and ants by having arms: limbs that are used not for locomotion (beyond infancy), but rather to reach and manipulate objects above the ground.

Spatially directed actions also potentially differ from terrestrial navigation in that the corresponding motor commands must specify the disposition of the entire organism in volumetric space – not only its location in point coordinates, but limb postures and joint angles. Perhaps this provides an avenue of reconciliation with the planar mosaic representation. Actions directed toward targets with particular metric relationships to the body may be designated as egocentric. Hence, they would lie specifically outside the scope of the current theory, which restricts itself to allocentric (environmentally referred) representations. This exclusion of metrically constrained behaviors from consideration is undermined, however, by the intrinsic ambiguity of frames of reference (Klatzky 1998). Humans flexibly compute transformations between self-referred and environmentally referred frames, even within a single task (Avraamides et al. 2004).

Lacking reliable behavioral or neural signatures that would allow us to designate actions as egocentric on the basis of their metric demands, it seems inappropriate simply to exclude them from a theory of volumetric spatial representation.

But wait – there is another feature of reaching, jumping, catching, and so on, that might render such behaviors distinct from those guided by a volumetric mosaic. Arguably, these behaviors are supported by perception, rather than representational abstractions. This argument might work if perceptually guided actions are somehow different from those guided by something called "representation," presumably including navigation. However, a position to the contrary has been put forward by Jack Loomis and the present authors, along with collaborators (for review, see Loomis et al. 2013). Our proposal stems from the fundamental idea that the perceptual system functions to create representations, and it is these representations that guide action.

We have used the term "spatial image" to refer to a particular type of representation that can support behaviors such as navigation and reaching, even when sensory systems no longer provide data about the physical world. For example, when a sound is emitted and then ceases, a spatial image of the sound's location still remains to support navigation (Loomis et al. 2002). The spatial image makes possible not only orienting and direct locomotion toward the target, but also spatial updating by means of path integration.

Importantly for present concerns, we have recently shown that the spatial image is three-dimensional and can be formed by actions with the arm, as well as by vision (Giudice et al. 2013). Subjects in our experiments formed representations of locations in volumetric space that they viewed, touched directly, or probed with a stick. They then walked without vision by an indirect path, requiring spatial updating, and touched the target at the appropriate height. Localization was not only accurate, but minimally affected by how the target representation was formed: The mean height error (signed distance between target and response height) was only 1, 9, 7, and 3 cm for targets originally explored with the hand, long pole, short pole, and vision, respectively. Precision, as measured by variability around the response location, was also little affected by mode of exploration.

These findings demonstrate several pertinent points. First, fully three-dimensional spatial representations were formed with high accuracy. Second, those representations conveyed metric data sufficient to support navigation, even in the absence of vision – that is, with perceptually guided homing precluded and spatial updating as a requirement. Third, the spatial image afforded action directed toward the object with the arms, as well as locomotion.

We have posited that human action capabilities require a metric representation of volumetric space that seems incompatible with the claim that terrestrial mammals are restricted to an impoverished representation of the third dimension, in the form of a loosely bound mosaic of planar maps. Although we have focused on humans, we see no reason not to extend these arguments to primates more generally, and we note that other mammals, such as squirrels and cats, routinely leap and jump to vertical target locations. We concede, however, the potential for constraints on human spatial representation. In particular, when our circumstances become more like those of animals confined to the ground plane (e.g., when travelling in a car), our cognitive maps, too, may provide only a local orientation relative to the direction of travel.

554-555 BEHAVIORAL AND BRAIN SCIENCES (2013) 36:5
[Commentary on Jeffery, K. J., Jovalekic, A., Verriotis, M., & Hayman, R. Navigating in a 3D world. *Behavioral and Brain Sciences*, 36(5), 554-555.]