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COGNITIVE NEUROSCIENCE

Different reference frames on different axes: Space and language in indigenous Amazonians

Benjamin Pitt[1]*, Alexandra Carstensen[2], Isabelle Boni[1], Steven T. Piantadosi[1], Edward Gibson[3]

Spatial cognition is central to human behavior, but the way people conceptualize space varies within and across groups for unknown reasons. Here, we found that adults from an indigenous Bolivian group used systematically different spatial reference frames on different axes, according to known differences in their discriminability: In both verbal and nonverbal tests, participants preferred allocentric (i.e., environment-based) space on the left-right axis, where spatial discriminations (like "b" versus "d") are notoriously difficult, but the same participants preferred egocentric (i.e., body-based) space on the front-back axis, where spatial discrimination is relatively easy. The results (i) establish a relationship between spontaneous spatial language and memory across axes within a single culture, (ii) challenge the claim that each language group has a predominant spatial reference frame at a given scale, and (iii) suggest that spatial thinking and language may both be shaped by spatial discrimination abilities, as they vary across cultures and contexts.

INTRODUCTION

Space is fundamental to human cognition, but people mentally represent space in qualitatively different ways. For example, it will be apparent to many readers looking at Fig. 1 that the chair is on the left and the ball is on the right. Although this egocentric (i.e., perspective-dependent) description may seem natural to some (*1*, *2*), it is far from universal. For example, among Tenejapan Tzeltal speakers of Mexico (*3*) or Yupno speakers of Papua New Guinea (*4*), the ball might be said to be "uphill" or "downhill" of the chair. Such descriptions use allocentric space, coordinate systems defined by features of the environment, independent of the observer's perspective, such as the slope of a mountain, the rotation of the planet (i.e., east and west), or the sides of a room (window side and door side). These egocentric and allocentric frames of reference (FoRs) constitute fundamentally different ways of representing the spatial relations among objects at any scale (*1*, *2*, *5*, *6*), from the monumental (e.g., the city is west of the mountains) to the minuscule (e.g., the freckle is on her left cheek). Although language groups typically have multiple FoRs at their disposal, they tend to use one type preferentially on a given spatial scale, according to cross-linguistic studies (*1*, *2*, *7*–*10*).

In addition to talking differently about space, people also show differences in spatial reasoning and memory, even when they are not using language, as revealed by a variety of behavioral tasks. People use different nonlinguistic FoRs to learn new dance routines (*11*), remember the location of hidden objects (*5*), track the path of moving objects through a maze (*3*) or across three-dimensional space (*12*), and reconstruct novel configurations of objects [(*2*); see Figs. 2 and 3]. The key manipulation in each of these tasks is the rotation of the participant between learning and testing, which reveals their implicit spatial strategies. For example, in spatial reconstruction tasks like those we use here (Fig. 2, right), participants learn to reconstruct a novel array of objects at a study table and then rotate 180° to face the test table, where they are asked to reproduce the same array. Critically, their behavioral response depends on which nonlinguistic FoR they use. If they use egocentric space, as is typical among adults in the United States and in other industrialized groups, their response array will be a 180° rotation of the original, preserving the position of array objects from the observer's perspective (i.e., objects that were on their right remain on their right; see Fig. 2). By contrast, if they use allocentric space, their response array will be a simple translation of the original (without rotation), preserving its spatial structure with respect to external coordinates (like the room or landscape), as is common in some unindustrialized groups, according to cross-cultural studies. In short, different FoRs define different ways of talking and thinking about space.

Beyond dictating the way people conceptualize space itself, FoRs also shape the representation of abstract, nonspatial domains like time and number, which people implicitly spatialize along a

Fig. 1. Where is the ball? In language elicitation tasks like this one (*9*), people use different spatial FoRs in their verbal descriptions (e.g., The ball is to the right/in front/east of the chair).

[1]Department of Psychology, UC Berkeley, Berkeley, CA, USA. [2]Department of Psychology, UC San Diego, San Diego, CA, USA. [3]Department of Brain and Cognitive Science, MIT, Cambridge, MA, USA.
*Corresponding author. Email: pitt@uchicago.edu

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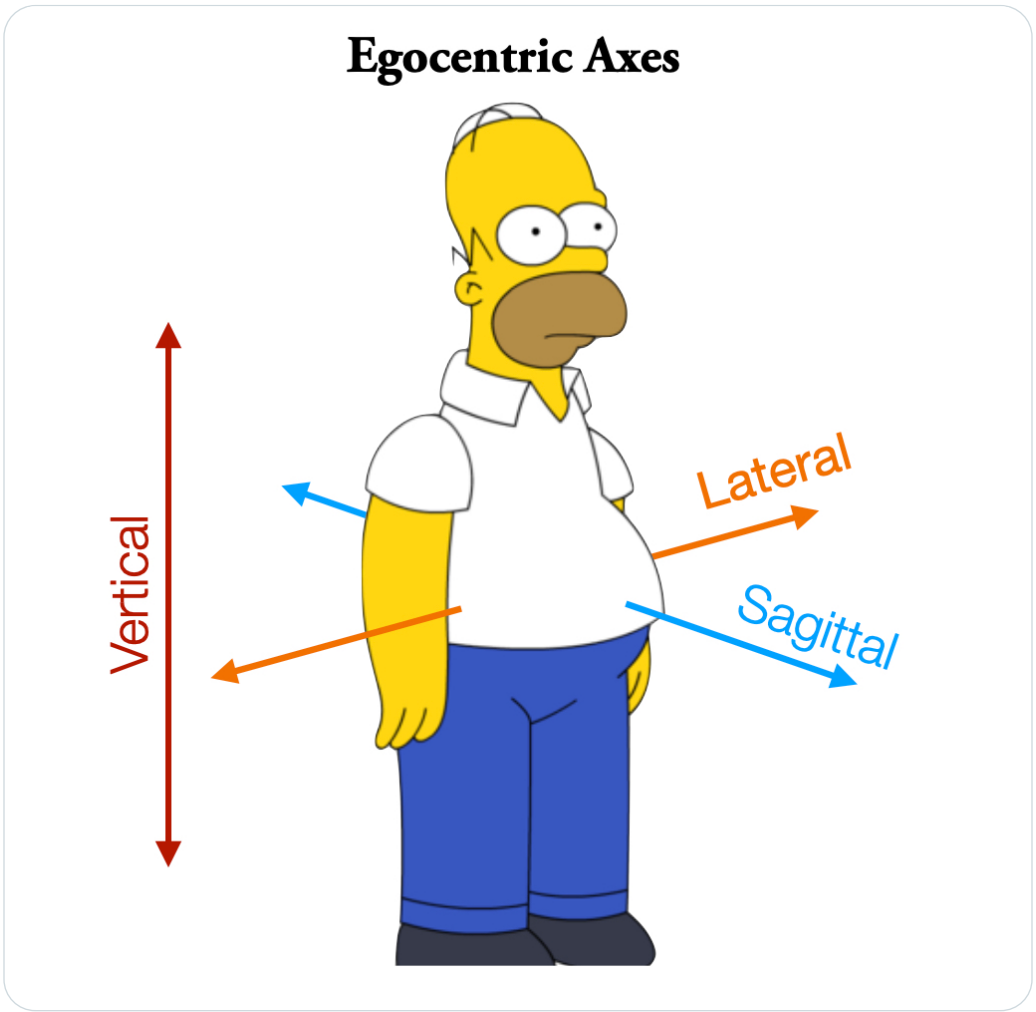
Space is a core part of our experience, but the way people conceptualize space differs in some amazing ways. Many groups think about space “egocentrically” - using the sides of their own bodies: i.e. left or right, front or back.



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But lots of cultures use the environment instead. So people might say you have a bug on your “north” ear or that the cup is “upriver” of the plate. Beyond language, this "allocentric" reference frame also shapes spatial MEMORY, like when people remember a path through a maze.

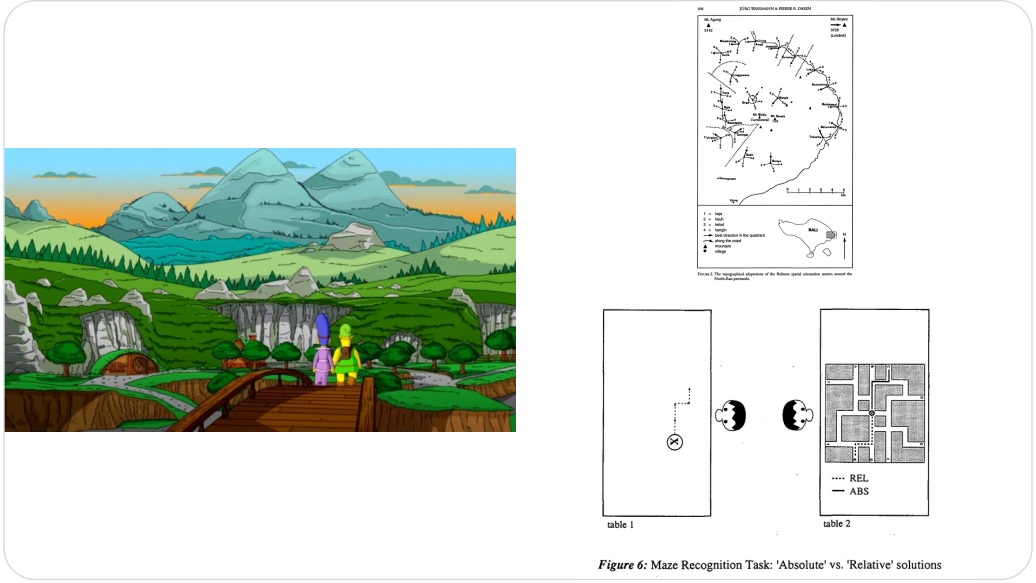

Figure 6: Maze Recognition Task: 'Absolute' vs. 'Relative' solutions

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Why do people use these different reference frames? What causes people to talk and think about space using the sides of their body vs. the features of the environment, even for the very same objects? (See amazing work by @DBMHaun @TylerMarghetis @kensycoop @asifa_majid @MPI_NL)

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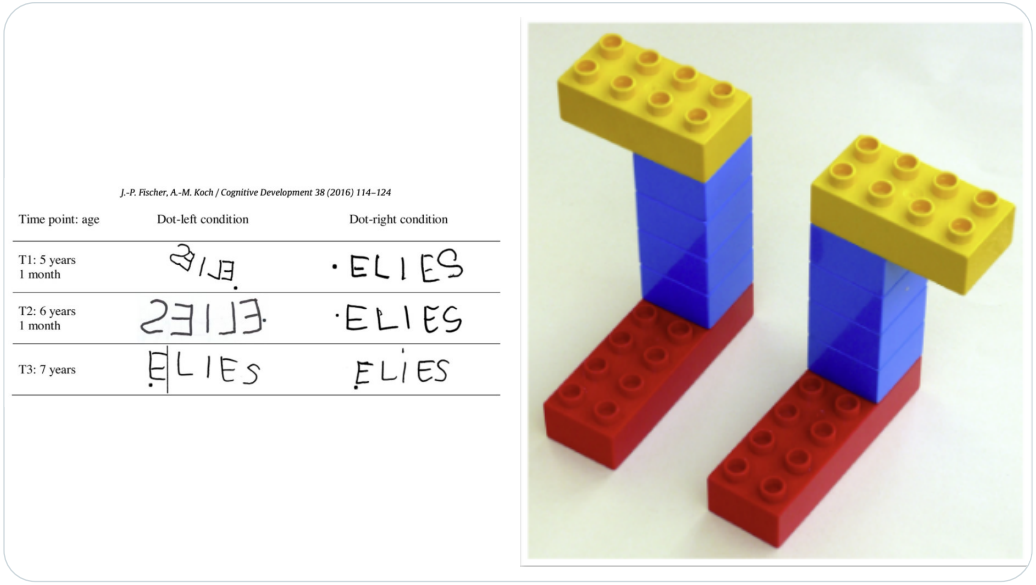
We suspected it might be about left-right space, the trickiest of bodily axes. This distinction is super hard for kids (think: b vs. d) and even for some educated adults (No, your OTHER left!). Many cultures don't make this distinction at all, and conflate mirror images/objects.



J.-P. Fischer, A.-M. Koch / Cognitive Development 38 (2016) 114–124

Time point: age	Dot-left condition	Dot-right condition
T1: 5 years 1 month	ELIES	·ELIES
T2: 6 years 1 month	ELIES	·ELIES
T3: 7 years	ELIES	ELIES

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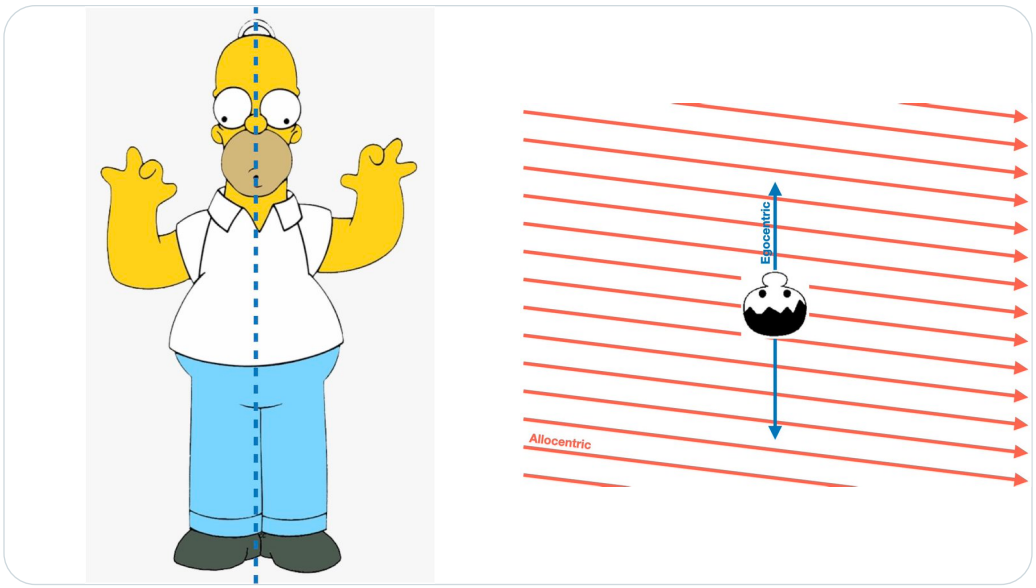
In our study, we tested people's use of spatial reference frames on two axes. If left-right spatial discriminability matters, then we figured they should prefer body-based space on the front-back axis but avoid it on the left-right axis, where body-based discrimination is harder.



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Our participants were indigenous Tsimane' adults, farmer-foragers who live in the Bolivian Amazon. Tsimane' people have words for left, right, front, and back, but spend large amounts of time navigating the jungle and its waterways. @Helen_E_Davis tinyurl.com/tvbpbwnh

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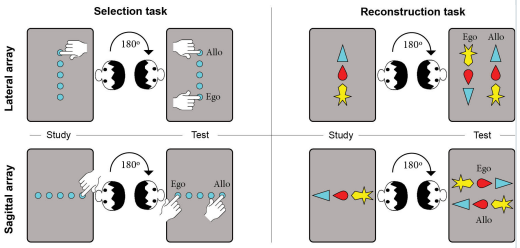
In our tests of spatial MEMORY, participants memorized an arrangement of objects and then turned around 180° and had to recall or reconstruct it from memory. The trick is that you get different answers depending on whether they used body-based space or environment-based space.



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In our test of spatial LANGUAGE, one participant described to another participant various arrangements of toy animals. We recorded which kind of spatial language they used: body-based (eg. the chicken is on the right) or environment-based (eg. the chicken is upriver of the pig).

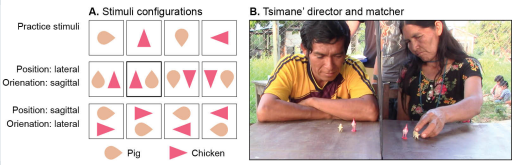

Table 1. Spatial language use by FoR in the director-matcher task.

Anchor	FoR (MesoSpace)	Proportion	Example
Egocentric	Direct	14%	The animals are facing me
	Relative	25%	The pig is on my side and the chicken is on the other side
Allocentric	Object-based	01%	The pig is on the chicken's right
	Landmark	29%	The pig is on the side toward the road
	Geomorphic	–	–
	Absolute	10%	The pig is upriver from the chicken
Other	Unclassifiable	20%	The pig is facing that way

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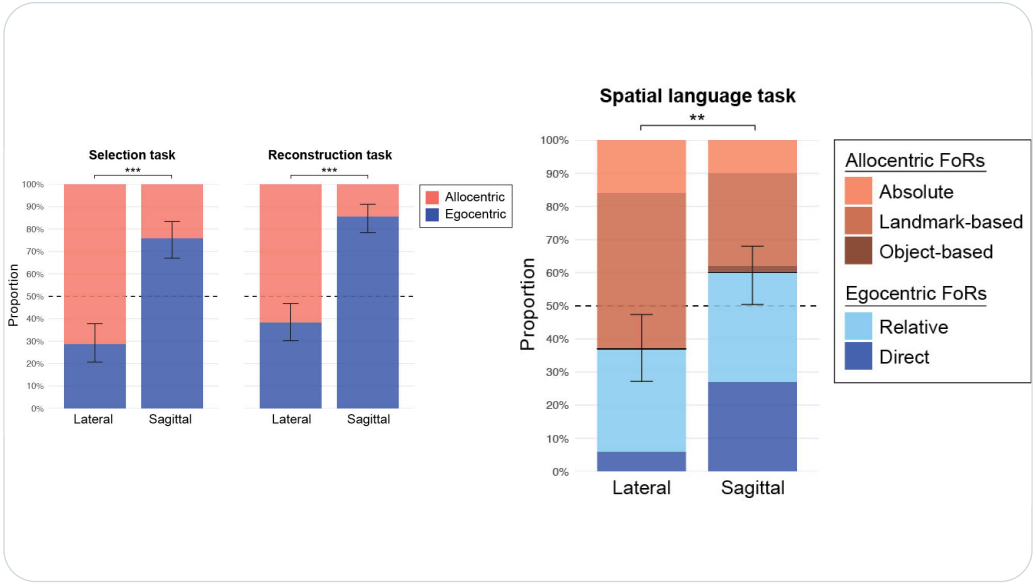
We found the same pattern in every task: Tsimane' adults preferred body-based (egocentric) space when dealing with the front-back axis but they largely abandoned it on the left-right axis, where they preferred environment-based (allocentric) space instead.



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This challenges the claim that language groups have a "predominant" spatial reference frame in memory or in language. Rather, different reference frames can predominate on different axes, even in the same person, in the same context, using the same stimuli!

3.0 Frames of Reference across modalities

So far, we have acquired some new facts: (i) not all languages use the same predominant frame of reference, (ii) there is a tendency for the frame of reference predominant in the language to remain the predominant frame of reference across modalities, as displayed by its use in non-verbal tasks of various kinds, unconscious gesture, etc. The results seem firm; they appear to be replicable across speech communities.

We suggest that one of the nonlinguistic determinants of FoR use may be people's perception of space, as governed by the spatial discrimination hypothesis. Since spatial relations (e.g., the relative locations of two objects) are experienced by people in context, they can all be defined by many spatial continua, some of which are egocentric and some of which are allocentric. On this account, all else being equal, people encode spatial relations using the spatial continuum along which those relations are easier to perceive or remember. If so, then the FoR that a person uses in a given context should vary according to the relative discriminability of the competing spatial continua; contexts or experiences that make a given continuum easier to perceive or remember should increase people's reliance on that continuum to structure their spatial language and spatial memory, whether that continuum is defined by the body or the

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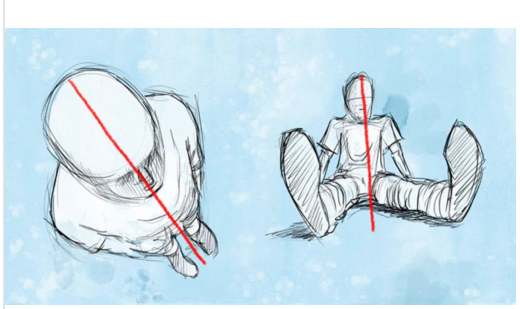
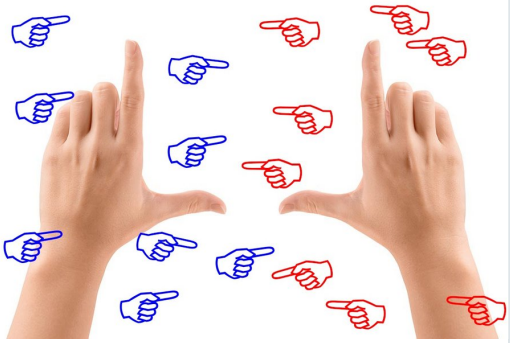
These findings suggest that spatial discrimination abilities may be one of the influences on the spatial reference frame people use in a given context: where your environment provides clearer distinctions than your body, you use the environment!





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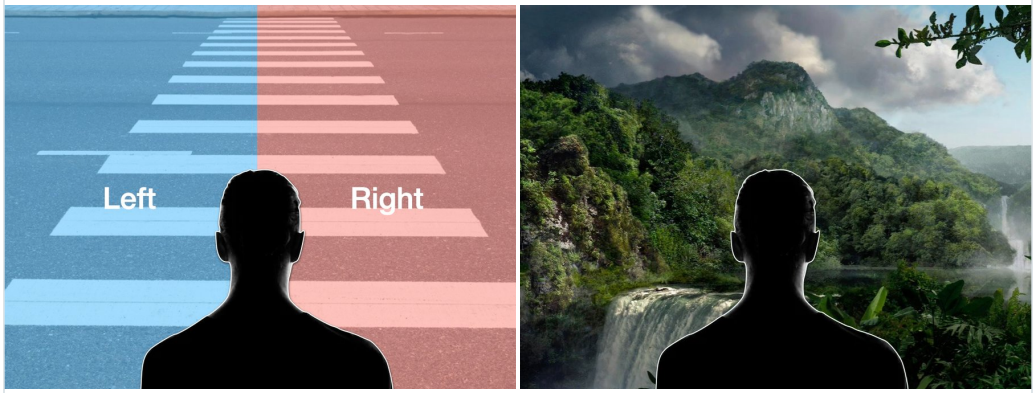
And since we know that people's left-right spatial discrimination abilities vary across cultures and over development, this idea can potentially help explain why we see differences in spatial reference frames across these contexts as well. @AlisonGopnik



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