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Ecological relativity of spatial cognition: Humans think about space egocentrically in urban environments

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Abstract

Humans make sense of space in a variety of ways. We can locate the world relative to our bodies, for instance, and thus adopt an 'egocentric' frame of reference for space. Or we can locate the world relative to an external frame of reference — the cardinal directions, perhaps, or salient geographical features such as mountains. Across contexts and cultures, people vary in the frame of reference they adopt to think and communicate about space. Here, we test an explanation of this diversity: Egocentric encoding is encouraged by dense urban environments, particularly when reasoning about small-scale space. We constructed a corpus of three decades of published studies of cross-cultural variation in spatial frames of reference ($N > 7000$ participants). Multilevel Bayesian models confirmed that egocentric encoding is more common in cities (vs. rural environments) and for small-scale space. Our conceptualization of space is shaped by the spaces we inhabit.

Keywords: space, frames of reference, linguistic relativity, environmental relativity

Introduction

Nearly a half-century ago, the anthropologist John Haviland video-recorded a man recounting in Guugu Yimithirr, an Australian Aboriginal language, a rousing tale of a boat that years earlier had capsized at sea. Two years after Haviland's recording, the anthropologist Stephen Levinson recorded the same man telling the same story. Haviland noticed that the storyteller's two accounts of the climactic moment, when the boat capsized, were indistinguishable in speech — but his hands suggested something interesting (Haviland, 1993). In the two retellings, the man gestured in very different ways to convey the same capsizing motion: left-to-right in one telling and forwards in the other. But in both cases, the gesture went east to west, as if he were reproducing the exact geographical orientation of the boat as it capsized. What's more, Haviland noted that Guugu Yimithirr does not have words to convey the spatial relations *left of* or *right of*. For decades, Western scholars had assumed that spatial cognition was, at its core, anchored to the body—left, right, front, back (Kant, 1768/1991; Levinson, 2003). But here, Haviland argued, were a people who reason, remember, and communicate about spatial relations in a fundamentally different way: anchored not to the body but to the external world.

Haviland's observation set off a flurry of research, with linguists, psychologists, and anthropologists all seeking evidence of cross-cultural variation in spatial cognition. And the evidence poured in (Levinson, 2003). It became clear that not all cultures privilege 'egocentric' coordinate systems for thinking and communicating about space. Instead, many cultures rely primarily on other coordinate systems that are not anchored in the body (Majid, Bowerman, Kita, Haun, & Levinson, 2004). Some adopt a geocentric system based on salient landmarks—mountains, valleys, waterways. Others rely on cardinal directions (e.g., north, east, south, west). These 'allocentric' coordinate systems share an approach to spatial relations anchored, not to the speaker's body, but to some external features or axes of the world at large.

Subsequent decades have seen heated debates about the nature and origins of this cognitive diversity. A core debate concerns the factors that encourage a culture to prefer one *spatial frame of reference*, as these coordinate systems are known. This is especially true for relations on the scale of 'table-top space' (Bohnemeyer et al., 2015; Haun, Rapold, Janzen, & Levinson, 2011; Li & Gleitman, 2002; Mishra, Dasen, & Niraula, 2003; Palmer, Lum, Schlossberg, & Gaby, 2017). While US Americans might use cardinal directions for large-scale descriptions — "drive west on the highway" — few would describe, say, a *dinner fork* as lying to the east or north of a nearby *bowl*. Yet in many cultures this kind of description can be normal, expected, or nearly obligatory (Majid et al., 2004). Why should people in some cultures nearly always use an egocentric frame of reference to make sense of small-scale space, while people in other cultures lack words to express *left* and *right*?

Much of the focus has been on the role of *language* in shaping spatial cognition, an instance of linguistic relativity (Bohnemeyer, 2020; Hanks, 2006; Pederson et al., 1998; Wolff & Holmes, 2011). Some have argued forcefully that language 'restructures' spatial cognition (Majid et al., 2004). Others have countered that all humans share a basic capacity to think of space in different coordinate systems, and rather mundane task features—such as ambiguous instructions that invite pragmatic inference—can push people to adopt one frame of reference over another (Li & Gleitman, 2002). If language does shape spatial cognition, its impact may be targeted. For instance, mastering the words for *left* and *right*

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might encourage people to adopt an egocentric frame of reference (Marghetis, McComsey, & Cooperrider, 2020; Shusterman & Li, 2016), even if they remain capable of reasoning otherwise.

But language is clearly not the whole story (Adamou & Shen, 2017; Marghetis, McComsey, & Cooperrider, 2014; Marghetis et al., 2020). Marghetis et al. (2020), for instance, investigated a linguistically mixed community in Oaxaca, Mexico, where speakers who were nearly monolingual in Isthmus Zapotec lived side-by-side with balanced bilinguals who spoke both Isthmus Zapotec and Spanish. Older speakers of Isthmus Zapotec in this community relied on an allocentric frame of reference in speech (McComsey, 2010), even lacking words that denote egocentric spatial relations like *left* or *right*, while Spanish habitually uses an egocentric frame of reference for small-scale space. Despite this linguistic variation, speakers who were Zapotec-dominant were no more likely than Spanish-Zapotec bilinguals to adopt an allocentric frame of reference in their non-linguistic reasoning (Marghetis et al., 2014).

Indeed, scholars have speculated that features of the local ecology may shape both language use and non-linguistic thought (Lupyan & Dale, 2016). In Majid et al.'s (2004) influential review of evidence for linguistic relativity in spatial frames of reference, they acknowledged that, across 20 different language groups, "there might be an association between urban-dwelling and use of a Relative [egocentric] FoR." There are a number of reasons to suspect an influence on spatial cognition of living in an urban or a rural environment. For one, an egocentric frame of reference may be more efficient in heterogeneous communities with high rates of migration. For geocentric frames of reference to work in conversation, for instance, both interlocutors must share knowledge of the relevant geological landmarks; this may be unlikely if the speakers are from different regions. Another reason that urban environments might drive people to adopt an egocentric frame of reference is that living there usually involves spending extended periods of time indoors. When urban dwellers do go outside, they may not have visual access to salient landmarks. An egocentric frame of reference may be more portable within the built environment of a large urban space (Bohnemeyer, 2017).

Cities may thus be factories for turning otherwise allocentric thinkers into egocentric ones. Pederson (1995), for instance, reported that urban Tamil speakers both spoke and reasoned using an egocentric frame of reference, while rural Tamil speakers preferred an allocentric frame of reference. While Pederson interpreted those results as evidence of linguistic relativity, it is also consistent with a shared causal impact of *urban dwelling* on both language and thought.

In the two decades since Majid et al.'s (2004) review, a variety of evidence has supported a role for urban dwelling, among other environmental factors, in spatial frames of reference (Mishra et al., 2003; Nölle & Spranger, 2022; Palmer et al., 2017, 2022). For example, residents of two rural South Asian villages use allocentric terms adapted to the local ecology — 'uphill'/'downhill' in mountainous Nepal, cardinal directions in a flat-terrain region of India — while city dwellers near the Indian village use egocentric terms as well, despite speaking the same language (Hindi) as the villagers (Mishra et al., 2003). Such linguistic and cognitive adaptation may be driven by environmental interactions. For atoll islanders who are more likely to live and work on the sheltered lagoon side of their island than the more hazardous ocean side, 'lagoonward' and 'oceanward' are salient allocentric concepts that become part of the linguistic repertoire (Palmer et al., 2017).

While striking, isolated case studies and comparisons of a small number of communities are limited as evidence for broad regularities in language and thought. Yet large-scale attempts to test for an association between ecology and spatial frames of reference are rare (Bohnemeyer et al., 2014; O'Meara & Pérez Báez, 2011). In one such study, Bohnemeyer et al. (2015) examined a sample of 11 language groups and found mixed evidence for an effect of local topography. We know of no attempts to test Majid et al.'s (2004) more specific conjecture — of an association between urban dwelling and adoption of an egocentric frame of reference — across a large number of geographically and linguistically diverse communities.

To address this issue, we constructed a databank that integrates the results from cross-cultural studies of spatial frames of reference. This is part of a larger initiative we refer to as ATLAS — *Abstract Thought and Language Across Space* — which aims to consolidate data from cross-cultural studies on spatial frames of reference as well as spatial construals of time and number. The current databank, ATLAS-Space (forthcoming), includes dozens of published studies of cross-cultural variation in spatial frames of reference. Here, we describe the basic details of this databank, and then leverage it to investigate whether living in an urban environment is systematically associated with egocentric spatial reasoning.

Methods

Databank creation We searched for published peer-reviewed papers in PsychInfo and Google Scholar using the search terms "spatial frame[s] of reference," "space," and "frames of reference." We also used the reference lists of papers to identify relevant authors who were conducting research on spatial frames of reference but using different terminology. Papers were only included in the databank if they studied the use of spatial frames of reference in at least one non-English-speaking sample. We concluded our literature search in mid-2021, so more recent articles are not included.

Trained analysts then coded each paper along a set of variables. Within each paper, analysts identified each cultural sub-sample, task, and fieldsite. They then coded: the study location; the sample size; the language of the cultural sub-sample; the type of task (e.g., gesture elicitation, object placement, spoken language production, etc.); the scale of the task (i.e., small-scale table-top space vs. large-scale geographical

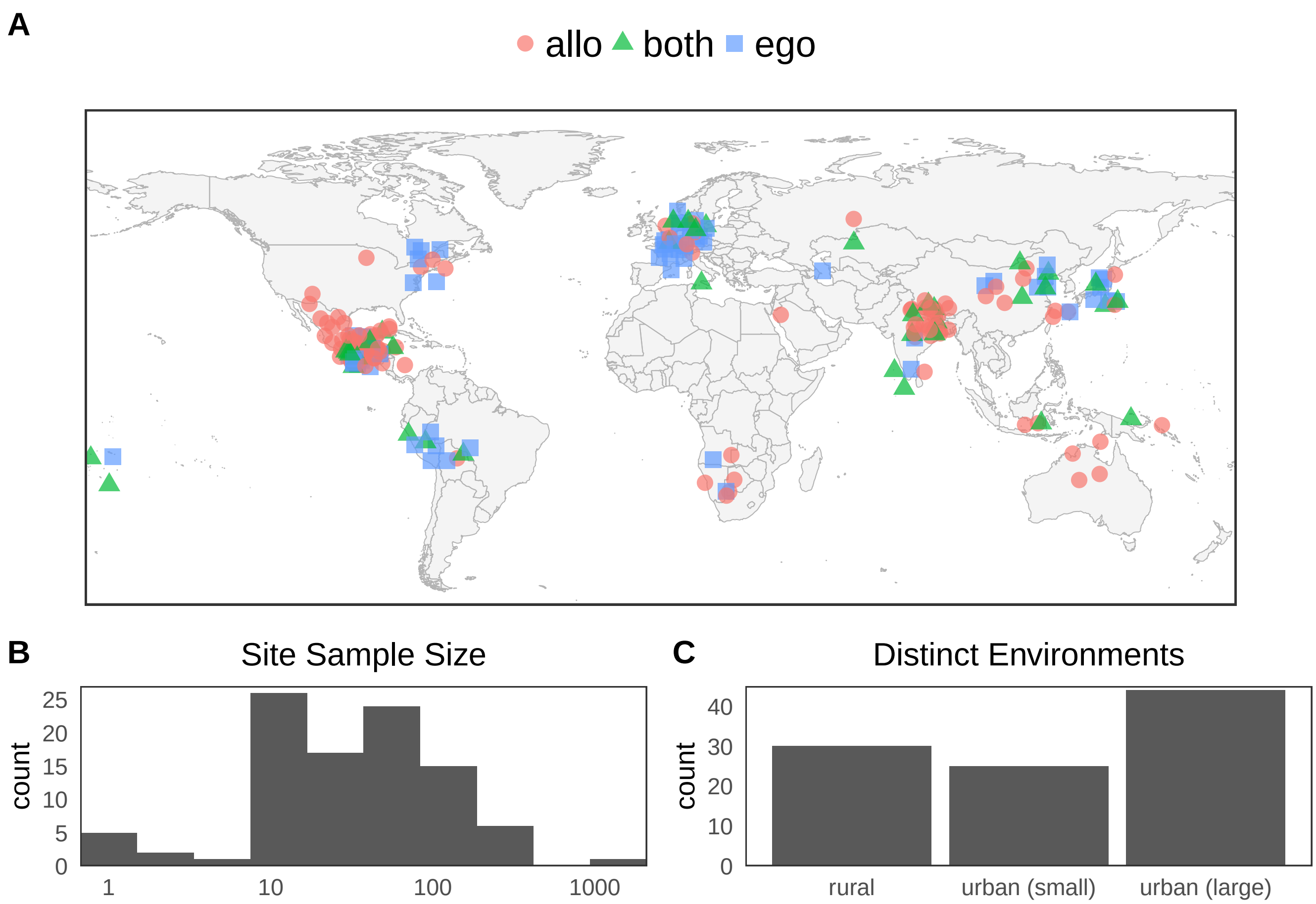

Figure 1: Global studies of spatial frames of reference. (A) Distribution of study locations. Each circle indicates one testing location. Color indicates the spatial frame of reference that participants adopted, whether by choice or imposed by the task. (B) Distribution of the total sample size collected at each distinct study location. Note that sample size has been log-transformed to visualize the heavy tail of larger studies. (C) Frequency of built environment across fieldsites.

space); and the spatial frame of reference (egocentric or allocentric) adopted by the majority of the sub-sample. If the authors of the paper did not find that the sample had a clear preference for either an egocentric or an allocentric frame of reference, the frame of reference was coded as 'both.' In cases where participants were forced to use a specific frame of reference, we coded whether their performance was described as good or bad by the authors. [1]

There is considerable debate about the best way to categorize spatial frames of reference (Bohnemeyer et al., 2015, inter alia), and different disciplines have adopted different taxonomies. To facilitate comparison across disciplines and theoretical frameworks, here we adopt a coarse-grained taxonomy that distinguishes frames of reference based solely on the 'anchor' that determines the coordinate system's axes (Danziger, 2010; Bohnemeyer et al., 2015). Frames of reference that are anchored to the body are egocentric; frames of reference that are anchored to some other entity are allocentric. We know this runs roughshod over many important distinctions; we consider it a necessary simplification for a multidisciplinary analysis on the scale attempted here.

A second team of analysts categorized each study location as either rural, urban small, or urban large. This followed a two-step process. First, if the study location was explicitly described by the authors as rural, a town/village (urban small), or a city (urban large), we used the author's determination to guide our assessment. If the paper included further details on the study site that corroborated the author's determination, we accepted it. If the authors did not specify the nature of the study location, we looked up the study location online and used resources such as images of the area, the presence of roads on Google Maps, and public records of population, density, and industrialization. For older studies, we included the year of publication in our searches to account for any subsequent urban development.

For every paper, a different analyst double-coded the spatial frame of reference adopted by the majority of partici-

[1]The current paper does not analyze effects of task type (e.g., gesture elicitation vs. object placement), though we are excited to investigate possible effects.

pants, the frames of reference that were allowed by the task, and performance in cases where participants were restricted to the use of a particular FoR. Agreement was high (mean agreement: 0.82, 0.88, and 0.89, respectively).

Results

Three decades of research on spatial frames of reference across cultures

ATLAS-Space integrates the published literature on cross-cultural variation in spatial frames of reference from the early '90s through 2021. We plan to make the databank publicly available soon. Future updates may include more recent articles and unpublished findings.

The current databank contains results from 54 papers, which reported studies conducted in 80 distinct study locations, in 29 countries, distributed across six continents (Africa, Asia, Europe, Oceania, North America, South America; Fig. 1A). Across study sites, sample sizes ranged across three orders of magnitude (Fig. 1B). All told, the databank contains evidence from 7229 unique participants[2]. Some participants completed multiple tasks, so that the databank has a total of 11,934 'person-task observations.' Studies were conducted in a variety of different communities, from rural to urban (Fig. 1C).

Participants in ATLAS-Space spoke 38 languages during studies (Fig. 2). Some languages were used by participants in multiple studies, and languages also varied in the number of participants they contributed to the databank (Fig. 2).

Preference for egocentric and allocentric frames of reference

Overall, allocentric frames of reference were adopted in more studies and by more participants ($n = 109$ study sessions, $n = 2726$ unique participants) than egocentric frames of reference ($n = 72$ study sessions, $n = 1958$ unique participants). This may reflect biases in sampling, task selection, and more.

We next investigated whether preferences for allocentric or egocentric frames of reference were associated systematically with key features of the spatial context: the scale of spatial cognition (i.e., small-scale table-top space vs. large-scale geographical space) and the nature of the local built environment (i.e., rural vs. urban). Most studies in the databank involved tasks on the scale of table-top space ($n = 198$), with only 20 studies on a larger scale. The most common field-site environment was large-urban ($n = 37$), followed by rural ($n = 20$), and small-urban ($n = 20$).

When participants were free to adopt any frame of reference, their choice was related systematically to both the scale on which they were thinking and the nature of the local built environment. We used a Bayesian logistic mixed effects model to predict whether the majority of participants in a given task had adopted an egocentric frame of reference.

[2] This does not account for participants who may have participated in multiple studies without their repeated participation being reported or even known by the authors.

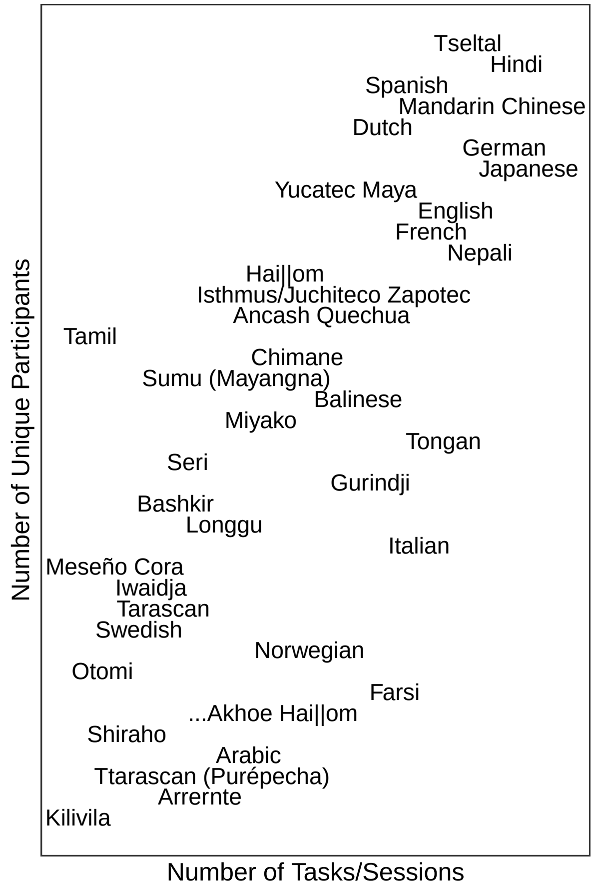

Figure 2: Languages in published studies of spatial frames of reference, organized by prevalence across task sessions (horizontal axis) and number of unique participants who used that language (vertical axis). Both axes show rank-ordering rather than raw values.

We include two fixed effects. The first was an ordinal variable that indicated whether the local environment was rural (0), a small urban community such as a town (1), or a large urban community such as a city (2). The second was an ordinal variable that indicated the spatial scale of the task, ranging from small-scale table-top space (0) to large-scale geographical reckoning (2). We included random intercepts for each citation, since many papers include multiple tasks or communities. The model was weighted by sample size, so that small case reports were less influential than large-scale studies.

As predicted, both the scale of the task (Fig.. 3) and the scale of the built environment (Fig. 4) predicted the adoption of an egocentric frame of reference on the task.

Small-scale tasks elicited more egocentric encoding (Fig.. 3). As the spatial scale of the task grew, the probability of egocentric encoding decreased ($b = -0.45 \pm 0.19$ *SE*, Bayesian Credible Interval $[-0.82, -0.08]$) while the probability of allocentric encoding increased ($b = +4.19 \pm 1.35$ *SE*, Bayesian Credible Interval $[2.12, 7.39]$).

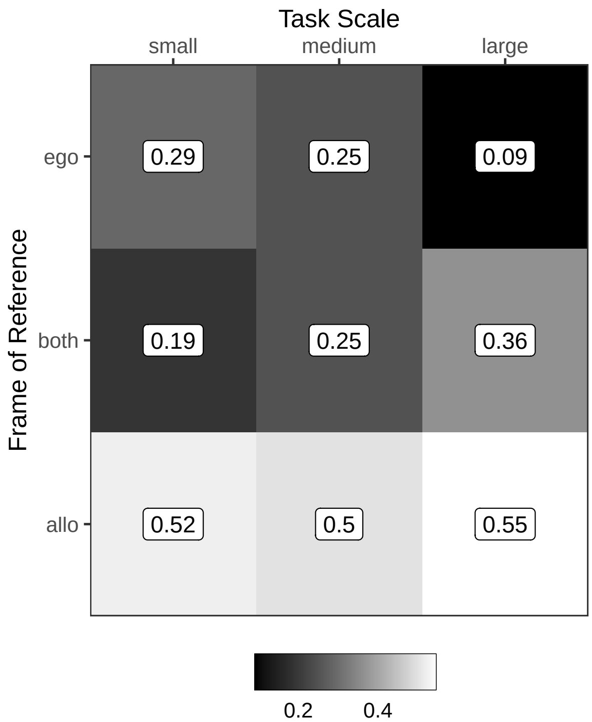

Figure 3: Spontaneously adopted spatial frame of reference (vertical axis) as a function of task scale (horizontal axis). Within each column, the numbers and underlying shade of grey indicate the proportion of studies, not accounting for sample size, in which participants preferred each frame of reference. (Note that proportions within each column sum to 1.) The probability of adopting an egocentric frame of reference (top row) increased monotonically as the spatial scale of the task decreased from large-scale geographical space to small-scale table-top space.

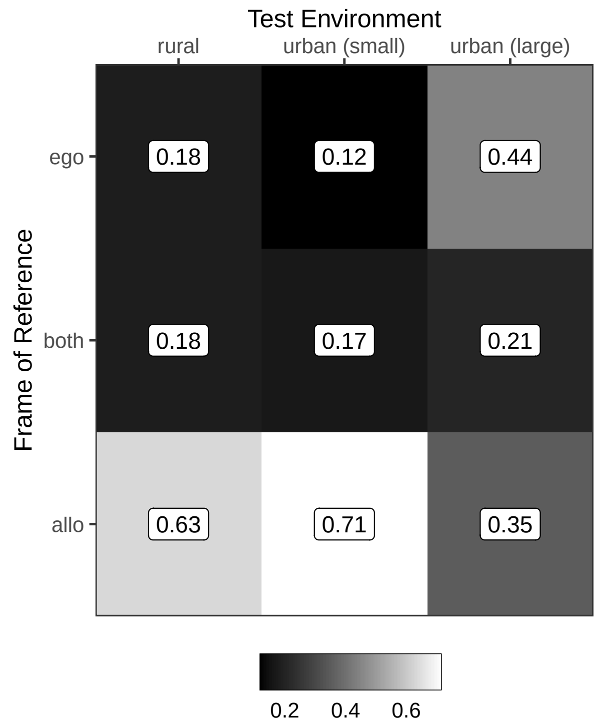

Figure 4: Spontaneously adopted spatial frame of reference in small-scale or "table-top" spatial cognition (vertical axis) as a function of environment (horizontal axis). Within each column, the numbers and underlying shade of grey indicate the proportion of studies, not accounting for sample size, in which participants preferred each frame of reference. (Note that proportions within each column sum to 1.) For samples collected in rural (left) and small-scale urban (middle) settings, the majority adopted an allocentric FoR. For samples collected in large-scale urban settings (right), the modal response was an egocentric FoR.

People in rural environments were less likely to adopt an egocentric frame of reference ($b = +0.84 \pm 0.04$ *SE*, Bayesian Credible Interval $[0.75, 0.92]$). Compared to people in rural communities, people living in a large urban setting were more than twice as likely to adopt an egocentric frame of reference ($p = .44$ vs. $p = .18$; Fig. 4, top row). Conversely, the probability of allocentric encoding decreased in urban settings ($b = -10.8 \pm 2.3$ *SE*, Bayesian Credible Interval $[-16.1, -7.3]$; Fig. 4, bottom row).

This pattern was driven by participants in rural and large-urban settings. Small urban settings were the most likely of all environments to elicit an allocentric frame of reference (Fig. 4, centre). We discuss this unexpected result below.

Discussion

Debates about the origin of cognitive diversity cut to the core of the human sciences. Here, we introduce a new large-scale dataset, ATLAS-Space, for investigating questions about diversity in spatial frames of reference. We used this databank to test for a link that has been hypothesized but never, to our knowledge, tested at scale: the association between urban environments and the tendency to adopt an egocentric frame of reference. People living in large urban environments were more likely to adopt an egocentric frame of reference and less likely to adopt an allocentric one. The spatial scale of the task itself also explained variation in preferred frames of reference; people are more likely to adopt egocentric frames of reference for small-scale tasks. The diversity of minds that we find around the world may reflect the diversity of spaces, of environmental niches, that we build for ourselves.

Why are urban environments associated with egocentric encoding?

Why might urban dwelling have this association with an egocentric frame of reference (Majid et al., 2004; Mishra et al., 2003; Palmer et al., 2017)? We discussed two possibilities in the Introduction. Urban environments may have more mixed, migratory populations; culturally heterogeneous communities may struggle to settle upon a set of shared allocentric landmarks. And people in cities spend more time indoors and when outdoors may have restricted visual access to salient landmarks that are essential for allocentric reckoning.

Here, we mention a few other accounts of the urban-egocentric link. For one, the urban-rural dimension in our databank may be confounded with formal education. Many rural samples in research on frames of reference are drawn from non-WEIRD communities without formal education[3]. Formal education and literacy may encourage people to reason about space egocentrically. Think of Cartesian coordinates and number lines: these run left-right, never east-west (Bohnemeyer et al., 2015; Danziger & Pederson, 1998; Lin, 2022). A second possibility is that cities bring people into contact with language communities that have and use words for *left*, *right*, and other egocentric relations. These words alone may serve as a kind of 'cognitive tool' that can scaffold the use of an egocentric frame of reference. Marghetis et al. (2020) found evidence for this account in a bilingual community in Oaxaca, Mexico, where mastery of the words for *left* and *right* was the strongest predictor of egocentric reasoning. Words for *left* and *right* may begin circulating within the larger cultural ecosystem of a city, even among people who do not speak the source language of the terms.

These considerations may help explain our unexpected result that the association between urban environments and egocentric encoding was driven entirely by participants in *large* urban settings. Participants in small urban settings, in fact, were even more likely to adopt an allocentric encoding than participants in rural settings. We consider three explanations of this unexpected result. For one, small-urban settings were the least common type of fieldsite in the ATLAS databank, so estimates for this setting may be more uncertain than those for the rural and large-urban settings. Second, many small-urban settings may actually have the exact features that have been argued to drive an allocentric preference: a culturally homogeneous and non-migratory population that spends much of their time outdoors. Third, there may be systematic differences in the daily activities and typical professions that are found in small- compared to large- urban environments, and the cultural practices that prevail in small-urban environments may rely more readily on allocentric encoding. Whatever the explanation, the unexpected result for small-urban fieldsites is a reminder that the categories of 'urban' and 'rural' are imperfect proxies for the more proximal mechanisms that drive the adoption of one frame of reference over another.

Implications for linguistic relativity

The current results, and the ATLAS-Space project more generally, may undermine some of the evidence for linguistic relativity in spatial frames of reference. Pederson (1995), for instance, found that urban-dwelling Tamil speakers in India used an egocentric frame of reference to reason about small-scale table-top space, while rural-dwelling Tamil speakers preferred an allocentric frame of reference. He interpreted this as evidence of linguistic relativity, since they also exhibited this preference in their speech. But if living in a city affects both language and thought, then the correlation between spatial language and spatial thought may reflect a common, environmental cause (Mishra et al., 2003).

This critique applies to much of the evidence for linguistic relativity. Traditionally, tests of linguistic relativity in spatial frames of reference have used a comparative method, wherein two communities known to differ in their spatial language are tested for differences in their spatial cognition (Haun et al., 2011). But any two communities will differ on countless dimensions besides linguistic ones, and all too often the group that uses an allocentric frame of reference in speech will also happen to live in a more rural environment (Majid et al., 2004). This introduces a massive confound, especially in light of the results reported here.

Future work will need to disentangle the various threads that make up our web of spatial reasoning. It may turn out that many instances of supposed linguistic relativity were actually instances of ecological relativity. But this kind of unicausal thinking — where we seek the 'true' cause of some cognitive difference — may do more harm than good. Ultimately, our preference for a particular spatial frame of reference is just one part of a much larger ecosystem of spatial practices (Hutchins, 2010). Living in a city may encourage people to think and speak egocentrically. But thinking about space egocentrically may increase the likelihood of moving to a city in the first place. Moreover, the urban-rural dimension may be systematically related to — and thus difficult to isolate from — not only education (Danziger & Pederson, 1998) but other factors such as subsistence style (e.g., farming vs. fishing; Palmer et al., 2017) and spatial activities like driving, sailing, and dancing (Nölle & Spranger, 2022; Tenbrink, 2022). In light of this complex ecosystem, the simple correlational approach we have taken here — despite its broad scope — offers only the most coarse-grained insights (Roberts & Winters, 2013). Future analyses of the ATLAS Databank should attempt to quantify this full ecosystem, including the rich web of interactions among sociocultural, ecological, and other variables. Combining the observational approach adopted here with experiments and computational modeling (Nölle & Spranger, 2022) will help illuminate the causal pathways that give rise to the cognitive diversity documented in our databank (Roberts, 2018).

As a cultural species, humans construct their own cognitive niches, which simultaneously reflect and mold their thinking. Our hope is that large-scale resources like ATLAS-Space, which pool the collective labor of decades of scientific investigation, will allow us to understand the richness of the bidirectional interactions that are the rule rather than the exception within ecosystems of thought.

[3]This is not to suggest that rural communities are always less educated than urban ones; we are just noting a contingent fact about the fieldsites in which research on spatial frames of reference has been conducted.

Acknowledgments

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