DOES ENVIRONMENT SHAPE SPATIAL LANGUAGE? A VIRTUAL REALITY EXPERIMENT

JONAS NÖLLE*, SIMON KIRBY, JENNIFER CULBERTSON, and KENNY SMITH

*Corresponding Author: j.nolle@sms.ed.ac.uk
Centre for Language Evolution, University of Edinburgh, UK

Variation in language structure can be motivated by external factors including the social, physical and technological environment (Lupyan & Dale, 2016) and communicative pressures (Coupé, et al., 2019). An example that is still hotly debated in this regard is spatial language: Speech communities vary in the Frames of Reference (FoR) they prefer in linguistic and non-linguistic tasks (Levinson & Wilkins, 2006; e.g., egocentric *the ball is to the left of the car* vs. allocentric/geocentric *the ball is downhill of the car*), but it is unclear whether this is just due to cultural drift (Majid et al., 2004) or environmental factors (Li & Gleitman, 2002). More recently, systematic fieldwork has found that for some languages, the use of a geocentric FoR can be predicted by factors such as topography, L2 contact, education, population density and subsistence style (Bohnemeyer et al., 2015; Palmer, et al., 2017). However, it is extremely hard to disentangle such factors and their individual causal contribution (Roberts, 2018). Here we isolate topography in a controlled laboratory setting to test whether a causal relationship between spatial language and environment can be detected.

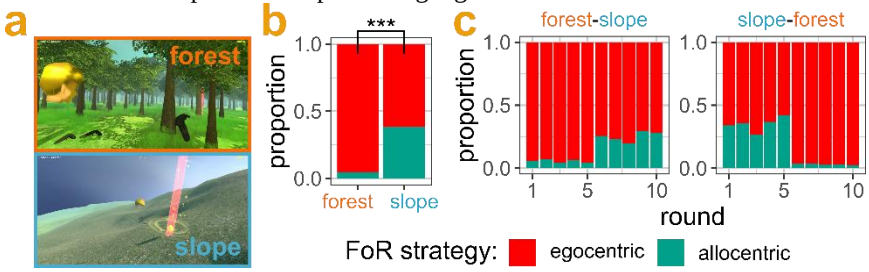

Figure 1 **a)** The two environments. **b)** Proportions of FoR strategy in both environmental conditions (Experiment 1) and **c)** over time across both experimental blocks (Experiment 2). See supplementary material for binomial linear mixed effect regressions.

For **Experiment 1** we developed *OrbHunt*, a referential spatial coordination game designed to test whether 21 dyads (n=42) speaking a predominantly egocentric language (English) would adapt their FoR depending on whether the environment in the game did or did not afford geocentric solutions. The task took place in

immersive Virtual Reality (VR) to provide participants with a naïve perspective and naturalistic sense of scale; participants were placed in a forest or mountainside environment and could communicate with each other by speech. Each round a *seeker* had to collect orbs located in the environment. The seeker could only see orbs which were sufficiently close (<5m). The second player, the *director*, could see the orb from any distance but could not collect it and was invisible to the seeker, thus unable to rely on deictic devices such as pointing; therefore, the director had to describe locations using spatial language. Each dyad played 10 rounds in one of the two environmental conditions (Fig 1a), switching roles at every round. Orb collecting success was identical across conditions. While dyads used a multitude of description strategies, overall, we found that dyads on the slope relied less on the egocentric FoR and utilized more allocentric strategies, e.g., relying on the geocentric bearings *uphill*, *downhill* and *across* (Fig. 1b).

An open question is why egocentric *left*/*right* is so widespread and dominant (e.g., in contact situations) even though comparative phylogenetic evidence suggests it is a recent cultural innovation (Haun et al., 2006) and harder to acquire than geocentric FoR (Shusterman & Li, 2016). We hypothesize that flexibility plays a role: a *left*/*right* FoR strategy is useful across many environments, while specific geocentric strategies may not be. **Experiment 2** tested whether egocentric strategies are more flexible by having 20 dyads play *OrbHunt* with a change in environments after 5 rounds (switch from forest to mountainside or vice versa). However, contrary to our hypothesis, while we replicated the experiment 1 result (less egocentric FoR on the slope), we did not find a significant difference between block orders; participants readily switched to allocentric FoR even when they had played in the forest first and on the slope second (Fig. 1c).

This could be due to English conventionally allowing both FoRs, meaning there was no cost to establishing a new strategy when switching environments. We will therefore discuss a new version of experiment 2 (currently in progress) that uses an artificial communication system, where spatial descriptors must be grounded in interaction and there is a cost to switching strategies. This will show whether dyads who first negotiate an egocentric strategy fair better when presented with a new environment. In sum, we found experimental evidence for topography affecting spatial language use, which could motivate geocentric systems in the real world. Our experiments are the first to study spatial language in large-scale (rather than table-top) environments and demonstrate how VR can be used to study factors shaping language under highly controlled conditions while maintaining ecological validity. Ongoing follow-ups address potential factors explaining the rise of egocentricity, such as modern, urban mobility.

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