Attention Shifts Caused by Linguistic Stimuli: A Bayesian Investigation of Spatial Associations Encoded in Language

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Background: Recent evidence suggests that spatial knowledge, apart from direct sensory input or verbal expressions [1], can be acquired implicitly, through statistical regularities in language use. These regularities are reflected in patterns of word co-occurrences, allowing semantic similarity –and metaphorically, 'distance'–between words to be inferred from their linguistic context. Such regularities are captured by Distributional Semantic Models (DSMs), which represent word meaning based on co-occurrence statistics in large text corpora [2, 3]. Despite their non-spatial nature, DSMs have been shown to recover spatial structure implicit in language, including geographical distances between cities [3–5]. To date, however, most evidence comes from concepts with inherently spatial referents, raising the possibility that language merely reflects sensorimotor experience. What remains unclear is whether language alone, as a non-spatial learning system, can encode spatial information when sensorimotor spatial grounding is weak, variable, or inconsistent. This study addresses this gap by testing whether words without explicit spatial meaning (1), but statistically associated with vertical locations in language, can bias spatial attention. Demonstrating such effects would provide evidence that linguistic experience itself encodes spatial structure, even in the absence of stable sensory grounding.

Method: Two preregistered experiments were conducted using words without explicit spatial meaning, selected to be uniformly distributed along LD, a corpus-derived measure quantifying association with vertical space (2). In Experiment 1 (N = 106), we employed a well-established attentional-shift paradigm [6, 7]. Each trial began with a centrally presented word, accompanied by a semantic judgment (abstract vs. concrete). A target figure then appeared in either the upper or lower visual field, and participants either responded to its shape or not depending on the previous decision (a go/no-go task). Experiment 2 (N = 101) emphasized verticality by modifying the target presentation: the figure appeared approximately 1.5° of visual angle from the central word and moved upward or downward until response or trial timeout (4000 ms). Bayesian regression models were used to test whether the effect of LD on response times and accuracy interacted with target position (Experiment 1) or movement direction (Experiment 2). We predicted faster and more accurate responses for compatible conditions, e.g., for targets appearing in or moving toward the upper visual field as LD increased (associated more with upper space), and slower or less accurate responses for lower targets or movements. We expected above-chance posterior probabilities for response times and accuracy.

Results: Bayesian regression analyses provided evidence for the predicted direction of the interaction between LD and figure vertical position, primarily in response times. In Experiment 1, the posterior probability of the LD × position interaction on response times was 0.953, and in Experiment 2, the posterior probability of the LD × movement direction interaction was 0.915, again supporting the predicted direction of the effect, although less strongly. In contrast, accuracy effects were weaker and less consistent: in Experiment 1, the posterior probability of the interaction (in the predicted direction) was 0.607, whereas in Experiment 2 it was 0.412, indicating substantial uncertainty and no reliable evidence for the predicted interaction.

Discussion: Taken together, these results suggest that spatial biases in attention need not arise solely from stable sensorimotor regularities but can instead emerge from the statistical structure in language use. This supports accounts in which linguistic experience constitutes an independent source of spatial information, capable of shaping attentional processes even when perceptual grounding is inconsistent.

(1) For instance, consider words such as *book* or *sugar*. A book can be encountered in the lower visual field (on one's lap or on a table) or in the upper visual field (on a shelf). Similarly, sugar involves downward hand movements when grasping it, but it can also be observed moving downward when poured into a cup. Thus, these concepts lack a fixed spatial location in experience (in contrast with *sun* or *grass*), yet they may still exhibit systematic spatial associations in language.

(2) Linguistic Differential (LD) is a measure of a word's relative association with vertical spatial concepts ("up" vs. "down") in linguistic experience. It is obtained with the following formula:

$$LD = [\cos(\vec{k}, \vec{up}) - \cos(\vec{k}, \vec{down})]$$

We computed this index as the difference between the cosine similarity of each word vector (k) with the averaged "upper space" vector (i.e., the centroid of words'vectors such as *up*, *upper*, *upward*) and its cosine similarity with the "lower space" vector. This index quantifies whether, in language experience, a target element is more related to the spatial words denoting upper vis-à-vis lower space: the higher the value, the closer a target word is to 'up' rather than 'down'.

References

[1] Taylor, H., & Tversky, B. (1996). Perspective in Spatial Descriptions. *Journal of Memory and Language*, *35*(3), 371–391. https://doi.org/10.1006/jmla.1996.0021

[2] Rinaldi, L., & Marelli, M. (2020). Maps and Space Are Entangled with Language Experience. *Trends in Cognitive Sciences*, *24*(11), 853–855. https://doi.org/10.1016/j.tics.2020.07.009

[3] Günther, F., Rinaldi, L., & Marelli, M. (2019). Vector-space models of semantic representation from a cognitive perspective: A discussion of common misconceptions. *Perspectives on Psychological Science*, *14*(6), 1006–1033.

[4] Louwerse, M., & Zwaan, R. (2009). Language encodes geographical information. *Cognitive Science*, *33*(1), 51–73. https://doi.org/10.1111/j.1551-6709.2008.01003.x

[5] Louwerse, M., & Benesh, N. (2012). Representing spatial structure through maps and language: Lord of the Rings encodes the spatial structure of Middle Earth. *Cognitive science*, *36*(8), 1556–1569. https://doi.org/10.1111/cogs.12000

[6] Estes, Z., Verges, M., & Barsalou, L. (2008). Head Up, Foot Down. *Psychological Science*, *19*(2), 93–97. https://doi.org/10.1111/j.1467-9280.2008.02051.x

[7] Shaki, S., & Fischer, M. (2023). How does language affect spatial attention? Deconstructing the prime-target relationship. *Memory & Cognition*, *51*(5), 1115–1124. https://doi.org/10.3758/s13421-022-01390-3