The Cultural Transmission of Spatial Cognition: Evidence from a Large-scale Study

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Abstract

We present the results of two studies of the use of spatial reference frames in speakers of 11 linguistic varieties. A series of mixed-models linear regression analyses of the responses to a referential communication task shows the significant factors in predicting frame use to be the participants' first and second-language, their literacy, the local topography and population density. This suggests that language can play an irreducible role in the transmission of practices of spatial reference and that such practices may be diffused through language contact. However, in a recall memory experiment, only speakers of varieties with an egocentric linguistic bias preferred egocentric responses. Both speakers of languages with a geocentric bias and speakers of varieties without a clear bias preferred geocentric responses. This unexpected finding is in line with a hypothetical mild innate pan-simian bias for geocentric cognition, which can be superseded by a learned egocentric bias.

Keywords: Linguistic relativity; spatial cognition; field studies; statistics.

Introduction

We present a large-scale investigation of the use of spatial reference frames in language and nonlinguistic cognition in speakers of 11 linguistic varieties of Mexico, Nicaragua, and Spain. Spatial reference frames are coordinate systems used to identify regions and directions in space. The axes of the coordinate system may be modeled after those of the body of an observer (egocentric frames), a reference entity (allocentric intrinsic frames), or some environmental entity or feature (allocentric extrinsic = geocentric frames).

The demonstration of a robust alignment between population-specific preferences in the use of spatial reference frames for small-scale space in discourse and recall memory (Levinson, 1996, 2003; Pederson et al., 1998; Wassmann & Dasen, 1998; Mishra, Dasen & Niraula, 2003; Haun et al., 2011; *inter alia*) has given rise to two competing interpretations. The use of particular frame types may be acquired, and speech, along with other forms of observable behavior, may play a role in its cultural transmission (Levinson, 2003; Majid et al., 2004; Le Guen, 2011). Alternatively, the use of all major frame types may be innately available population-independently and usage preferences in both discourse and nonlinguistic cognition reflect shallow, readily mutable ontogenetic adaptations to factors of topography, population geography, literacy, and education (Li & Gleitman, 2002; Li et al., 2011).

To test these competing hypotheses, we studied the use of reference frames in discourse and recall memory in members of 11 populations: speakers of six Mesoamerican languages, two non-Mesoamerican indigenous languages, and three varieties of Spanish, the dominant contact language spoken in the same geographic region. These studies apply designs to the largest number of populations targeted in a single study of this nature to date that are similar in kind to what has become standard in this line of inquiry. A more important innovation, however, is the use of mixed-models linear regression analysis to discern which factors predict an individual participant's behavior.

Frame use in discourse: Ball & Chair

We conducted a referential communication task (Clark & Wilkes-Gibbs, 1990) to assess the use of reference frames in discourse by members of the 11 populations.

Materials and method

The Ball and Chair (B&C) task is a photo-matching game consisting of four sets of 12 photos depicting a ball and

chair in different spatial configurations. A dyad of speakers sits side-by-side divided by a screen to prevent sharing of a visual field. Each speaker has identical sets laid out in front of them. One speaker (the 'director') then selects and describes each photo so that the 'matcher' can select its match from their set. Roles are reversed between sets.

Participants

Data is presented from 11 language groups: six from within the Mesoamerican *sprachbund*, two indigenous languages spoken just outside the *sprachbund* – Seri and Sumu, and three varieties of Spanish. The Spanish-speaking communities were selected to closely match the demographics of the indigenous communities. Table 1 shows the localities of data collection, as well as the distribution of sex and age.

Table 1: Participants by language, site, age, sex, and study (MA – Mesoamerican; NMA – non-Mesoamerican indigenous; Sp. – Spanish).

Language	Locality	Age < 30 / ≥ 30		Sex M / F	
		B&C	NA	B&C	NA
Tseltal (MA)	Chacoma	7/3	9/7	6/4	9/7
Yucatec (MA)	Yaxley	2/6	4/10	4/4	7/7
	Felipe Carrillo Puerto	0/2	0/1	1/1	0/1
Mixe (MA)	Ayutla	3/7	4/8	3/7	3/9
Otomi (MA)	San Ildefonso Tultepec	0/8	0/5	1/7	1/4
Zapotec (MA)	La Ventosa	4/8	4/8	3/9	3/9
Tarascan (MA)	Santa Fe de la Laguna	4/6	7/9	4/6	8/8
Seri (NMA)	El Desemboque	1/9	0/2	2/8	1/1
Sumu (NMA)	Rosita	2/8	4/6	5/5	4/6
Mexican Sp.	San Miguel Balderas	n/a	5/6	n/a	4/7
Mexican Sp.	Chimalacatlán	6/4	n/a	3/7	n/a
Nicaraguan Sp.	Rosita	0/8	5/13	2/6	4/14
European Sp.	Barcelona	2/6	6/4	1/7	6/4
Total		31/75	48/79	35/71	50/77

Coding

The directors' locative descriptions were analyzed and coded for frame use, using an eight-way classification: allocentric intrinsic, egocentric intrinsic, allocentric extrinsic (geocentric), egocentric extrinsic ('relative'), gravitational geocentric (vertical), intrinsic-vertical aligned, intrinsic-relative aligned, and topological (frame-free). Aligned descriptions are true in multiple frame types (Carlson-Radvansky & Irwin, 1993).

Analysis

To keep the director constant, we limited the following analyses to sets 2 and 4 of the task. In order to investigate the distribution of the dependent variables, we constructed a spatial model that assigns to each director a point in octo-dimensional space based on the frequency with which they used the eight types of descriptions. We then explored this model using multi-dimensional scaling. In order to examine how participants' responses clustered, pairwise distances were calculated as the Manhattan distance between them. A three-dimensional MDS model was computed. These dimensions were paired with the original response matrix and tested for correlations using Spearman's Rho (Baayen, 2008). It was found that the first dimension correlated with two of the response types: geocentric and relative. The correlation with the set of geocentric responses was positive (Spearman's Rho:0.869, p<.001) and the correlation with the set of relative frequencies was negative (Spearman's Rho: -0.840, p <.001). We also found a correlation between the frequency of topological uses and the second dimension of the MDS plot (Spearman's Rho: -0.947, p<.001).

The MDS analysis shows that participants differentiate themselves most strongly in their use of relative, geocentric and topological descriptions. However, topological relations are perspective-free and do not play a role in the further analysis. We are now left to ask which factors predict the use of relative and geocentric descriptions. We examined this in a second step of the analysis.

Impact of the predictor variables In order to test which of the predictor variables made significant independent contributions to a dyad's use of relative and geocentric frames, we ran a series of logistic regression analyses with the probability of a director choosing these frame types as the dependent variable and first language (L1), second language (L2) use, reading/writing frequency, education level, local topography, and population density as independent variables. Our data set contains too many individual languages for parsimonious modeling, so languages were grouped according to areal-linguistic affiliation, creating a three-leveled categorical variable grouping the languages of the Mesoamerican Sprachbund, the two non-Mesoamerican indigenous languages, and the three varieties of Spanish.

Reading and writing frequencies and education levels were assessed on four-valued scales, L2-Spanish use on a three-valued one. Population density and topography for each field site and were calculated from census data (INE 2010; INEGI 2010; INIDE 2005) and maps (Hernández Santana, Hubp, & Ortiz Pérez, 2007, p.c.). Density was assessed as the population of each community divided by its area according to Google Earth. Topography is treated as a categorical variable based on elevation levels and broad geomorphological features. We distinguished among orogenic belts, volcanic belts, central high plateaus, continental shelf, and coastal basins and transgressions.

We implemented generalized linear mixed-effects models (Jaeger, 2008) using the ARM package in R (Gelman et al., 2012) with individual language and dyad as random effects.

In total, twelve models were run. Six models were run per independent variable: geocentric uses and relative uses.

We ran separate models based on the participants' self-estimates of their literacy and education levels and frequency of reading, writing, and (for the speakers of the indigenous languages) use of L2-Spanish and on the field researchers' estimates of the same values based on their individual knowledge of the communities and participants. We found only one major discrepancy between these data subsets: there was an effect of L2-Spanish use in the models based on self-reported participant data (summarized in Table 2), but not in those based on researcher estimates. The models that included L2-Spanish use as a predictor variable excluded L1-Spanish speakers.

Table 2: Summary of the eight regression models of the B&C responses based on self-estimated participant data. Models that include L2 use exclude L1-Spanish speakers. (Significance: 0 '***' 0.001 '**' 0.01 '*' 0.05 '#' 0.1).

	Models	1	2	3	4	5	6	7	8
Literacy	Reading	✓	✓	✓	✓				
	Writing					✓	✓	✓	✓
L2 Use	Included			✓	✓			✓	✓
Response	Geocentric	✓		✓		✓		✓	
	Relative		✓		✓		✓		✓
Results	L2 Use				**				**
	Language Group	***	***		***	***	***		***
	Density			*	***		#	*	***
	Topography	*			**	#	#		**
	Writing							*	
	Reading								

Results and discussion

All 11 linguistic varieties are lexically and grammatically compatible with the use of all major reference frame types. Therefore, the selection of a frame type in response to a given picture was not constrained by the lexicon or grammar of any of the languages. We can thus ask to what extent this choice was predicted by the speaker's native language, their use of a second language, or the nonlinguistic variables Li and Gleitman suggest. The variables that made a significant independent contribution to predicting the probability of a relative or geocentric description of a given picture in at least some of the models were first language group (Mesoamerican vs. non-Mesoamerican indigenous vs. Spanish variety), the frequency of use of Spanish as a second language, the frequency of writing, and the two geographic variables. Correlations at or above .6 solely occurred between population density and several levels of the topography variable (in most models) and between the Mesoamerican and non-Mesoamerican indigenous languages (in one model). In these cases, even if the algorithm picked one of the correlating variables as producing a significant effect to the exclusion of the other, in actual fact it was not considered possible to reliably distinguish between the effects of the two variables. The principal limiting factors in such instances are sample size and the types of variables involved.

Frame use in recall memory: New Animals

We also conducted a recall memory experiment with members of the 11 populations, employing the array reconstruction paradigm (Levinson, 1996, 2003; Levinson et al., 2002; Li & Gleitman, 2002; Wassman & Dasen, 1998; Mishra et al., 2003; Haun et al., 2011). This paradigm tests the preference for egocentric vs. geocentric reconstruction of stimulus arrays from memory after the participant's body has undergone rotation. Preference designs do not assess the participants' <u>ability</u> to use particular frame types (Li et al., 2011). However, the usage or practice of spatial reference has been as much at the heart of the neo-Whorfian debate as the ability to acquire and use different strategies. Usage is in part a matter of culture, and the question to what extent spatial cognition is influenced by culture is a point of significant controversy between the opponent camps in the debate.

Materials and method

Individuals are shown a row of three toy animals. When they signal that they have memorized the array, it is taken away. After a delay of 30-60 seconds, they are rotated 180° and led to another table, where they are handed four animals and asked to recreate the array. Participants performed six trials each, and researchers recorded the order and facing direction of the reconstructed arrays.

Participants

See Table 1 above for the localities of data collection and the sex and age of the participants.

Coding

Responses were coded for orientation and order of animals (options were *geocentric*, *egocentric*, or *neither*). Three possible error types were: (1) neither order, (2) neither orientation, (3) wrong animal selection. Trials with error types 1 and 3 were excluded from analysis, as were all trials for participants who performed more than 2 of these errors. 20 percent of participants (36 of 184) were excluded for these errors. 13 percent of trials (101 of 786) were excluded for these errors.

Analysis

We ran linear mixed effects analyses using the ARM package in R, testing the probability of egocentric and geocentric reconstructions as the dependent variable. We ran two models for each variable, modeling literacy on self-estimated reading vs. writing frequency. We tested for the same range of independent variables as in the models of the linguistic data discussed above. Table 3 summarizes the findings.

Table 3: Summary of the eight regression models of the NA responses based on self-estimated participant data. Models that include L2 use exclude L1-Spanish speakers (Significance: 0 '***' 0.001 '**' 0.01 '*' 0.05 '#' 0.1).

	Models	1	2	3	4	5	6	7	8
Literacy	Reading	✓	✓	✓	✓				
	Writing					✓	✓	✓	✓
L2 Use	Included			✓	✓			✓	✓
Response	Geocentric	✓		✓		✓		✓	
	Egocentric		✓		✓		✓		✓
Results	L2 Use								
	Language Group	***	*	*		***	*	*	*
	Density		**	*			*	*	
	Topography	*	**			**	*		#
	Writing								
	Reading								

Results and discussion

Correlations above .6 occurred between education and reading/writing and between population density and several levels of the topography variable. Some topography levels also correlated with one another in some models. Our models cannot reliably distinguish between effects of the correlated variables.

The models of the probability of geocentric reconstructions show language group, topography, and writing to be significant independent factors. This suggests that language is an influence on frame choice in recall memory that cannot be reduced to covariation with nonlinguistic variables, contra Li and Gleitman (2002) and in line with the neo-Whorfian hypothesis of Levinson (1996) and others.

However, the only predictor variable that produced a significant effect in the models of the probability of egocentric reconstructions was writing. Topography played a marginally significant role. There was, however, no significant language effect.

The explanation for the absence of a linguistic effect in the egocentric models is not hard to find: 10 of the 11 populations – all except for the European Spanish speakers - showed a preference for geocentric responses. There was thus a bias in favor of geocentric coding in the recall memory task that cut across our three language groups. The presence of a preference for geocentric reconstructions among Mexican and Nicaraguan Spanish speakers is not predicted by the neo-Whorfian hypothesis, since these populations did not show a preference for geocentric representations in the linguistic task.

General discussion

The Linguistic Transmission Hypothesis

Our studies have shown language to be far from the only significant determinant of frame use, as an orthodox Whorfian interpretation (Whorf, 1956) of the alignment between frame use in linguistic and nonlinguistic tasks across languages might suggest. However, if the contribution of language to frame use in the Ball and Chair study could be reduced to the covariation between language and the nonlinguistic variables Li and Gleitman (2002) suggest, then our regression models should not have found a significant language group effect at all. We hypothesize that language plays a significant role in frame use because speech is an observable behavior that can serve in the cultural transmission of practices of spatial reference, along with other observable behaviors, such as gesture (Le Guen, 2011).

This view of language as a transmission system for cognitive practices neither entails nor precludes the existence of language-on-thought effects from knowledge of the grammars and lexicons of the languages of the world (knowledge as opposed to use, or competence as opposed to performance). To distinguish this view from (weak (non-deterministic) or strong (deterministic)) interpretations of the Linguistic Relativity Hypothesis, we propose the Linguistic Transmission Hypothesis (LTH): "Using any language or linguistic variety – independently of its structures – may facilitate the acquisition of cultural practices of nonlinguistic cognition shared among the speakers of the language." Bohnemeyer et al. (ms.) cite Levinson (2003: 210-213; 301-325) as a precursor of the LTH. Spatial frames of reference afford a particularly suitable test case for the LTH, since they are not lexicalized or grammaticalized in language, but rather are themselves cognitive practices that underlie the interpretation of both linguistic and nonlinguistic spatial representations.

Direct support for the LTH comes from the impact of the familiarity with the use of Spanish as a second language we observed. The speakers of the indigenous languages in our sample used relative frames more frequently in their native languages the more frequently they also used Spanish as a second language. This points toward habituation to the use of relative frames diffusing through contact with European languages such as Spanish. To our knowledge, our study has produced the first quantitative evidence of the diffusion of linguistic and cognitive practices through language contact.

Literacy, assessed in terms of the frequency of reading and writing, was also a significant predictor of frame use. This variable makes a significant independent contribution to the use of geocentric frames, but not to that of relative ones. High levels of literacy seem to depress the use of geocentric frames. This confirms earlier findings (Danziger & Pederson, 1998).

A pan-simian geocentric bias?

To further probe the geocentric array reconstructions not predicted by linguistic data from members of the same populations, consider Table 4, which presents data collected with both tasks from members of five Spanish-speaking populations, including three groups of Mexican Spanish speakers. The three Mexican Spanish data sets were collected in small rural communities outside Mexico City.

These communities were selected to meet three criteria: absence of (i) current and (ii) historical contact with indigenous languages and (iii) comparability with the indigenous communities of our sample in socio-economic terms and in terms of average literacy and education levels. The recall memory data included in the models presented above is that collected in San Miguel Balderas in Mexico State. As Table 4 shows, referential communication data collected from five dyads in the same community show a preference for intrinsic coding over both relative and geocentric coding. This data was not included in the models of the linguist data presented above, since the participants did not switch roles between trials in the same way in which this was done with the other populations, making it impossible to match productions to speaker data in the way required by the models. The Mexican Spanish data we used in the linguistic models was recorded in Chimalacatlán, Morelos.

Table 4: Responses to the two tasks from members of five Spanish-speaking communities.

Community	B&C	#	%	NA	#	%
Santa Ines	Relative	49	34	Egocentric	42	58
	Intrinsic	24	17	Geocentric	28	39
	Geocentric	2	1			
San Miguel Balderas	Relative	50	17	Egocentric	10	24
	Intrinsic	133	46	Geocentric	22	52
	Geocentric	8	3			
Chimalacatlán	Relative	87	52	Egocentric	N/A	N/A
	Intrinsic	45	27	Geocentric	N/A	N/A
	Geocentric	4	2			
Rosita	Relative	84	35	Egocentric	41	33
	Intrinsic	81	34	Geocentric	73	58
	Geocentric	5	2			
Barcelona	Relative	131	45	Egocentric	63	75
	Intrinsic	61	21	Geocentric	14	17
	Geocentric	0	0			

A third Mexican Spanish data set was collected in Santa Ines, Mexico State, comprising both linguistic (three dyads) and recall memory data. As the table shows, these participants preferred relative representations in discourse, just as the European Spanish speakers, and egocentric array reconstructions, again just as the Europeans. This data was not included in the models because we did not collect information about the participants' levels of literacy and education. These participants were tested in the very beginning of the project, before the analyses presented above were conceived. Since recruitment had been anonymous, we were unable to go back to the participants later and instead had to rerun the tasks with new participants, giving rise to the other two data sets. A Fisher's exact test shows the distribution of egocentric and geocentric reconstructions across speakers from Barcelona and Santa Ines, which prefer relative coding in language, vs.

Rosita (Nicaragua) and San Miguel, which do not, to be highly significant (one-tailed p < .0001).

The Nicaraguan L1-Spanish-speaking participants produced a pattern similar to the one of the speakers from San Miguel Balderas: there was no clear evidence of a bias in the linguistic task, with relative and intrinsic descriptions occurring equally frequently. Yet geocentric reconstructions were preferred over egocentric ones. This is not unlike the distributions observed in the indigenous languages. The only indigenous group that produced predominantly geocentric responses in both studies was the Isthmus Zapotec speakers. In all other populations, intrinsic responses dominated over geocentric ones in the referential communication task, with relative responses in second place among the Seri speakers and in third behind geocentric ones in all other groups. Yet, all of these populations preferred geocentric array reconstructions.

Previous studies already noticed this mismatch in Yucatec speakers, beginning with Bohnemeyer and Stolz (2006). Le Guen (2011) hypothesizes a gesturally rather than verbally transmitted geocentric bias, whereas Bohnemeyer (2011) postulates task specificity. However, neither of these proposals predicts the distribution observed in the present study.

A possible explanation in line with all the data presented here – and, as far as we know, with all available evidence concerning the use of reference frames across populations – comes from research on non-human primates. Haun et al. (2006) present evidence pointing toward geocentric representations of small-scale space being processed more accurately than egocentric representations in recall memory in all five genera of great apes and in German preschoolers. They suggest that this presumably innate bias may be superseded in specific human populations by a learned, culturally transmitted egocentric bias.

Supporting evidence for an innate, but nevertheless malleable geocentric bias comes from developmental studies, which suggest that children growing up in geocentric populations acquire geocentric terms very early, possibly even before topological relations (Brown, 2001; Brown & Levinson, 2000, 2009; de Leon, 1994). Spatial cognition in animals may have evolved primarily for the task of tracking the position of the animal and other animals vis-à-vis the environment. The egocentric perspective may be more useful for organisms with a human-like degree of control over their immediate environment. Since the computational primitives involved in calculating all frame types are the same – axes, angles, and distances – this system originally "designed" for geocentric coding would be easily reconfigurable for egocentric cognition.

In combination with the Linguistic Transmission Hypothesis, the hypothetical innate, but malleable geocentric bias correctly predicts our data: only the populations that show a relative bias in the linguistic task also prefer egocentric array reconstructions, whereas all other populations prefer geocentric coding in recall memory.

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