Cognitive biases and social coordination in the emergence of temporal language

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Abstract

Humans spatialize time. This occurs within individual minds and also in larger, shared cultural systems like language. Understanding the origins of space-time mappings requires analyses at multiple levels, from initial individual biases to cultural evolution. Here we present a laboratory experiment that simulates the cultural emergence of space-time mappings. Dyads had to communicate about temporal concepts using only a novel, spatial signaling device. Over the course of their interactions, participants rapidly established semiotic systems that mapped systematically between time and space. These semiotic systems exhibited a number of similarities, but also striking idiosyncrasies. By foregrounding the interaction of mechanisms that operate on disparate timescales, laboratory experiments can shed light on the commonalities and variety found in space-time mappings in languages around the world.

Keywords: language evolution; space and time; abstract concepts; social coordination; cultural evolution

Introduction

Human language stands out for its capacity to refer to things that are elsewhere in space or time: “How was the movie?”. Beyond this capacity for “displaced” reference (Hockett, 1960) to concrete objects, we can also talk about entities that are entirely abstract: the future, the number five, and so on. Indeed, natural languages deploy nuanced, systematic strategies to refer to concepts for which there are no stable perceptual referents. What are the origins of the linguistic structure that allows us to communicate about the abstract? Here, we present a novel experiment to help answer this question, focused on the language of *time*.

A test domain: Time

The conceptual domain of Time is a critical test case for theories of language evolution because, while temporal concepts are entirely divorced from perception, they are also highly structured. The concepts *next week* and *yesterday* cannot be distinguished perceptually; the events of next week will, soon enough, be those of yesterday. Temporal concepts lack stable perceptual referents. And yet our conceptualization of time is highly structured, consisting of at least three distinct facets: duration, order, and deixis (for a review: Núñez & Cooperrider, 2013). Temporal duration refers to *amount* of time. In English, we have a rich lexicon of duration terms (second, hour, year, etc.). Temporal order refers to the *sequence* in which events occurred. Pregnancy occurs *before* birth; celebrations come *after* victories. Temporal deixis refers to the placement of events in relation to *now:* past, present, or future. A celebration can be occurring now, have occurred in the past, or occur in the future. All three facets can be combined during temporal reference, so that we can speak of a *day-long* party happening *before* your next birthday (i.e., in the *future*).

Across a number of languages, a recurring strategy is to use *spatial* words to communicate about time (e.g., Haspelmath, 1997; Lakoff & Johnson, 1980). For instance, in English you can say *“**back** in the ‘50s”* or *“look **forward** to the weekend*,” mapping past to back and future to front. How do such systems of conventionalized space-time mappings emerge? Some argue that we have an innate bias to associate space, time, and number (e.g., Walsh, 2003). On this view, cross-domain associations in language arise from neural resources that are shared across space, time, and number. Others argue that a variety of abstract domains (including time) share structural and relational features with space and thus can easily be aligned (e.g., Gentner, 1983). Once aligned, structure from the domain of space—and its associated language—is projected to the domain of time. A third view is that regularities in experience create cross-domain associations in the minds of individuals, so-called “conceptual metaphors” that, in turn, influence how we think and talk (Lakoff & Johnson, 1980). While each of these mechanisms may play a role, none on their own can account for the combination of universality and variability that we find in the languages of the world. To understand the emergence of conventionalized space-time mappings in communication, we need to consider the interplay of mechanisms that operated at various timescales (c.f., Núñez & Cooperrider, 2013).

***Table 1**: The full set of meanings used in the experiment. Meanings ranged in duration from brief moments (‘now’) to limitless periods (‘future’), and included durations (‘day’), sequential relations (‘day before’), and deictic periods defined relative to the present (‘yesterday’).*

	Duration	***Sequence***	***Deictic***
Moments	*‘second’*		*‘now’*
Days	*‘day’*	*‘day before’* *‘day after’*	*‘yesterday’* *‘today’* *‘tomorrow’*
Year	*‘year’*	*‘year before’* *'year after’*	*‘last year’* *‘this year’* *‘next year’*
Periods		*‘before’ ‘after’*	*‘past’ ‘future’*

Sources of structure

Our approach adopts a view of language as a complex adaptive dynamical system (Steels, 1997; Beckner et al., 2009), which foregrounds the complex links between the level of the individual (language users in a community and their individual cognitive biases) and the level of the population (languages as dynamic systems). The field of language evolution has developed experimental methods that help to isolate some of the relevant mechanisms that play a role in these links (Scott-Phillips & Kirby, 2010). These methods help explain how cognitive biases and cultural evolution together may account for some of the structures we see in language (Christiansen & Chater, 2008; Kirby, Griffiths & Smith, 2014). For instance, past work has shown that linguistic structure can emerge from pressures induced by transmission and social coordination (Kirby, Cornish & Smith, 2008; Caldwell & Smith, 2012; Verhoef, 2012; Kirby et al., 2014). Transmission of a language causes signals to be filtered through the cognitive constraints of new learners; only signals and structures that are easily learned and remembered will be reproduced and passed on. In addition, as people interact repeatedly, they have to align their signals to communicate expressively (Garrod, Fay, Lee, Oberlander & MacLeod, 2007; Fay, Garrod & Roberts, 2008; Fusaroli & Tylén, 2012; Caldwell & Smith, 2012). Signals in this case originate as conventions on the basis of social coordination and shared communication history.

Here, using methods that simulate language evolution in the lab, we study the interaction between initial biases and cultural evolution in the emergence of space-time mappings in communication.

Methods

Inspired by work in which novel semiotic systems emerged through interaction, we used a *dyadic communication game paradigm* in which pairs of participants communicated about temporal concepts using a novel signaling device, a vertical touch bar that recorded finger movement sequences. Since communication was restricted to these novel signals, successful communication required the negotiation of novel conventions for representing temporal concepts in vertical space. Undergraduate students (n = 16) at the University of California, San Diego participated for partial course credit.

Time concepts

The time concepts to be communicated fell into three broad categories: Duration (e.g. ‘day’), Sequence (e.g. ‘before’) and Deictic (e.g. ‘tomorrow’), as shown in Table 1. Meanings in one category often had closely related meanings in others. Some meanings were distinguished only by whether they involved a tenseless sequential relation rather than being placed specifically in the past, present, or future (e.g., ‘year before’ *vs.* ‘last year’). Others involved specific durations (e.g., ‘day’) that are located relative to now (e.g., ‘today’). While natural languages have evolved ways to encode these subtle distinctions, it is not trivial to develop a novel system of signals that is simple enough to learn but complex enough to communicate successfully about all concepts.

Signals

Pairs of participants communicated using a vertical bar on a touch screen (Fig. 1), which recorded and replayed brief signals. Signals consisted of exactly 5 seconds of vertical movements of a bubble within the bar. The bubble moved continuously, following the location of the participant’s index finger. If the finger was lifted during recording, the bubble would stay in the same location until the bar was touched again or the 5 second limit was reached. A vertical signalling system was chosen because English does not make conventional use of verticality to describe time[1].

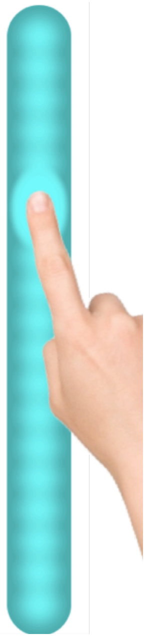

***Figure 1**: Signalling with a vertical bar on a touch screen*

Procedure

Participants were seated in separate testing rooms. They sat in front of touch screen computers that were connected

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[1] Cultural artifacts sometimes associate time with vertical location, but experience with such artifacts is unlikely to generate strong, reliable associations, since artifacts vary considerably in how they map time to space. Calendars place earlier events above later ones. Many internet blogs place earlier posts below the most recent ones. Facebook combines both conventions: earlier Timeline posts are *below* more recent ones, but earlier comments are placed *above*.

through a local network. Communication was thus limited to spatial signals displayed on the vertical touch bar.

The design of the interaction game followed Verhoef, Roberts & Dingemanse (2015). On each trial, a participant was either the 'signaller' or the 'recipient', switching roles after each trial. Trials began when a meaning was displayed on the signaller's screen. The signaller then had to record a signal for this meaning using the vertical bar. Once they were happy with their signal, it was sent to the recipient, who could replay the signal on their own screen. On the basis of this signal, the recipient had to guess the intended meaning; they indicated their selection by touching the meaning on a panel that showed all meanings. Players received feedback after each trial, including both the intended target meaning given to the signaller, and the guessed meaning selected by the recipient.

Each dyad completed four rounds of eighteen trials. Each meaning appeared once per round in a random order, but such that, over the course of the experiment, each participant took the role of signaller for each meaning twice.

Results

Communicative success

We first asked whether participants could successfully communicate about these temporal concepts using the vertical signaling device. From the very first round, accuracy was above chance and improved throughout the experiment, increasing monotonically with each round: M_1: 20.1%, M_2: 21.5%, M_3: 45.1%, M_4: 47.9%. We analyzed this improvement using a mixed-logit model of accuracy on each trial, with a fixed effect of round, random effects of Dyad and Meaning, and by-dyad and by-meaning random intercepts and slopes for Round. The fixed effect of Round was centered to reduce colinearity. This model confirmed that accuracy increased significantly over the four rounds, $\beta = .699$, SE= .167, $p < .001$. Thus, despite the novelty of the task, participants quickly negotiated a set of signals that allowed them to communicate successfully.

Duration and Spatial Extent

Participants could produce a wide range of possible signals, and there was considerable between-dyad signal variability. However, there were also consistent patterns across dyads. Signals made consistent use of *spatial length* to communicate relative temporal duration (Fig. 2). Signals for 'second', a relatively "short" duration, typically involved very little motion and were restricted to the centre of the bar. By contrast, 'day' was signalled using repeated vertical movements that took up half the bar, while signals for 'year' typically covered the entire bar. Thus, *longer durations* appeared to elicit signals that occupied *more space* along the vertical axis. No dyads used the opposite strategy, associating longer *durations* with shorter *spatial extents.* To quantify this pattern, meanings with a definite duration were grouped into three categories by temporal duration: Short, which included 'second' and 'now'; Day, which included 'today', 'day after', etc.; and Year (we excluded 'before,' 'after,' 'past,' and 'future' from this analysis). For each signal, we calculated the maximal space used (MSU) as the distance between the highest and lowest points of the signal. Was there a mapping between duration and spatial extent that was consistent across dyads? We analyzed the MSU of each signal using a linear mixed-effects model, with a fixed effect of Temporal Duration, random effects of Dyad and Meaning, and by-dyad random slopes for temporal extent. As predicted, there was a systematic relation between temporal duration and MSU, with long temporal durations (e.g. 'year') associated with more space (full model compared to reduced model without temporal extent, $\chi^2 = 23.76$, $p < 0.0001$).

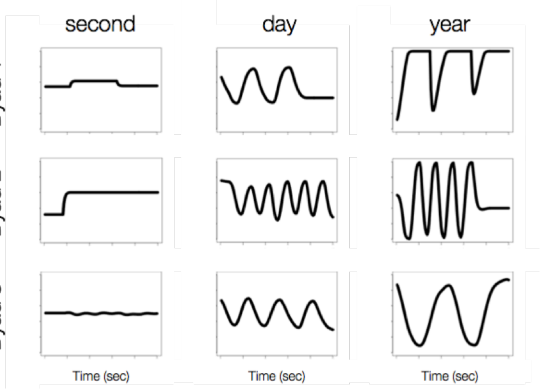

***Figure 2**: Duration signals used by three dyads. Each signal is shown as a timeseries (y-axis = vertical location).*

More complex signal-meaning structure

If social interaction and coordination resulted in more complex, systematic conventions, then we should be able to observe patterns in the relations between signals and meanings. Dyads typically settled on a consistent location or movement direction to distinguish meanings that were in the *past* from those in the *future,* but differed in how they mapped past/future to location. About half the pairs used downward movements for *future* and upward movements for *past*, while other pairs reversed this mapping, using *upward* movements for *future*. There was also evidence of sequential patterning, in which dyads combined signals that had been used previously (e.g., 'before,' 'after,' 'year') to create new composite signals (e.g., 'year before,' 'year after'; Fig. 3). Note, however, that these new conventions governing compositionality did not merely reproduce the conventions of English, but sometimes reversed the sequential order (e.g., 'after' followed by 'year').

These internal systematicities can be quantified by relating meaning similarity to signal similarity. Following Kirby, Cornish & Smith (2008), we calculated the Pearson's correlation between pairwise distances in the meaning space and corresponding distances in the signal space. For each dyad, we thus computed two measures for each pair of signals: *Signal Distance,* which captured the similarity of

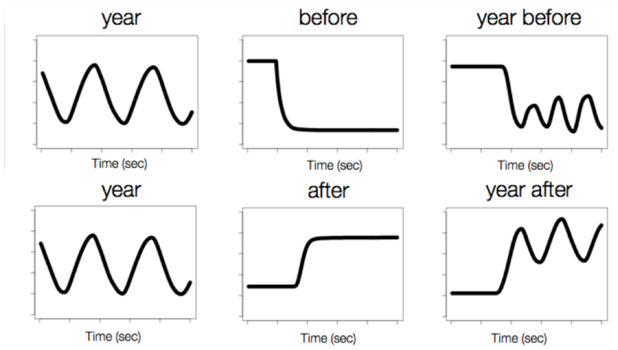

Figure 3*: Compositional structure in the signals of a dyad.*

the signals, and *Semantic Distance,* which captured the similarity of the associated target meanings.

First, the ***Signal Distance*** (Δ_{signal}) combines the total amount of space used (i.e., MSU) with the focal location of the signal, or Location of Maximal Density (LMD). The former, MSU, is critical because, as described above, this was used consistently to communicate temporal duration. The second, focal location, appeared to be used to contrast past/future or before/after. This was calculated as the point of maximal touch density, between 0 (bottom) and 1 (top). Each signal was thus associated with two values, MSU (total space) and LMD (focal location), and the Signal Distance between two signals (*s1, s2*) was the Euclidian distance between these two points:

$$\Delta_{\text{signal}} = \sqrt{(LMD_{s1} - LMD_{s2})^2 + (MSU_{s1} - MSU_{s2})^2}$$

Second, the measure of ***Semantic Distance*** (Δ_{semantic}) between two meanings combined three aspects of semantic difference: Duration (Δ_{dur}), Order (Δ_{ord}), and Class (Δ_{class}). We calculated Duration Difference (Δ_{dur}) by ordering each meaning by its temporal extent, from short or instantaneous durations ('now,' 'second'), to days ('today'), to years ('year after'), to unlimited ranges (e.g., 'past,' 'future'). For instance, for 'second' and 'next year,' the pairwise Duration Difference would be:

$$\Delta_{\text{dur}} = |\text{instant} - \text{year}| = |1 - 3| = 2.$$

Order Difference (Δ_{ord}) captured differences in relative temporal order. Sequence and deictic meanings were categorized by relative order: past/before < now < future/after. We collapsed 'past' with 'before', and 'future' with 'after,' based on the finding that English speakers associate these concepts with the same spatial locations (Casasanto & Jasmin, 2012). If both meanings were sequence or deictic, Order Difference was defined as along this ordinal scale; otherwise, if either of the meanings was a duration, Order Difference was defined as 0. For instance, for 'today' and 'next year,' Order Difference would be:

$$\Delta_{\text{ord}} = |\text{after/future} - \text{now}| = |3 - 2| = 1.$$

Lastly, we defined pairwise Class Difference (Δ_{class}) as 1 if the meanings belonged to different semantic classes (i.e., duration, sequence, deictic), and 0 if they belonged to the same class. Thus, for 'year after' and 'next year', $\Delta_{\text{class}} = 1$, since 'year after' is sequence but 'next year' is deictic. Semantic Distance summed these three components, and is thus similar to an edit distance between two meanings, accounting for duration, order, and semantic class.

Compositional structure is indicated by a positive correlation between pairwise Signal Distance (Δ_{signal}) between all possible pairs of signals in a system and pairwise Semantic Distance (Δ_{semantic}) between the associated target meanings (Kirby et al., 2008). This was calculated for each dyad and each round. Structure increased over the course of dyads' interactions (Fig. 4). A linear mixed-effects model of this measure of compositionality, with Round as a fixed effect and Dyad as a random effect, showed an increase of 0.37 (S.E. +/-0.13) each round. Comparison to a reduced model without a fixed effect of Round confirmed that structure increased significantly ($\chi^2 = 6.36$, $p < 0.05$). To compare this observed structure to the structure we might observe by chance, the actual systems produced by dyads in our experiment were compared to 1000 simulated systems, in which the signal values were created randomly. The dotted line in Figure 4 indicates the upper limit of the 95% confidence interval for random data; values above this show a significant amount of internal structure. While most systems were not significantly structured in the first round, by the final round almost all systems had significantly more structure than chance.

Sensitivity to regularities in the semiotic system

Participants quickly became adept (Accuracy in Round 4, *M* = 48%; chance < 6%). This could be because they were simply memorizing each signal-meaning pair, without having internalized any of the structure documented above. However, if participants *were* sensitive to the systematic use of space to represent different aspects of time, then we should be able to find evidence of this in their errors: incorrect guesses should be semantically related to target meanings.

To quantify the systematicities in participants' errors, we

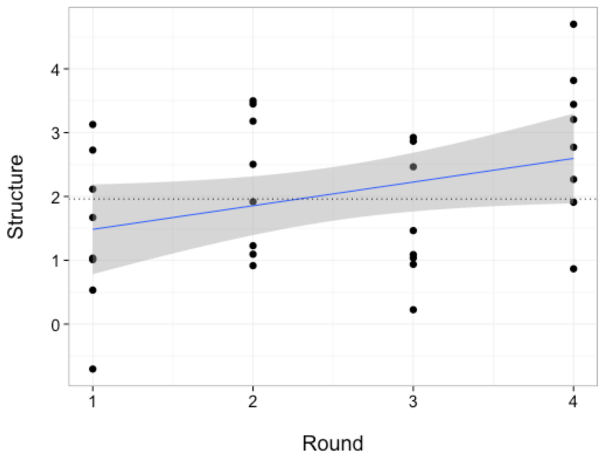

Figure 4: *System internal structure (y-axis) increased with social interaction. Each point represents a system deployed in a particular round by one dyad.*

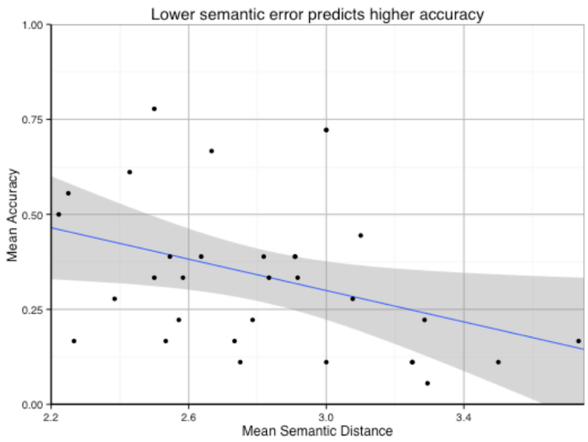

Figure 5*: Dyads were more successful overall if their incorrect guesses were semantically related to the correct target meaning. Each dot represents one round.*

used our measure of Semantic Distance (Δ_{semantic}), described above, to compare incorrect guesses to correct target meanings. If dyads gradually learned the conventions of their emerging semiotic system (e.g., compositional structure), then errors should become gradually more systematic, with incorrect guesses becoming systematically closer to the correct target over time.

Indeed, Semantic Distance between target meanings and incorrect guesses decreased monotonically over the course of the interaction: $M_1 = 3.13$, $M_2 = 2.79$, $M_3 = 2.75$, $M_4 = 2.61$. To analyze this effect, we used a mixed effects model with a cumulative logit link function, since Semantic Distance is an ordered, categorical variable. The full model had a fixed effect of Round, random effects of Dyad and Target Meaning, and random intercepts and slopes. Semantic Distance shrank significantly as the game progressed, $b = -0.55$, $z = -4.43$, $p < .001$. This full model was better than a model without a fixed effect of Round, likelihood ratio = 10.5, $p = .001$.

A reduction in Semantic Distance, moreover, was accompanied by an increase in communicative success: Dyads were significantly more likely to guess correctly overall if their *incorrect* guesses were semantically closer to the target meanings. According to a linear mixed-effects model of mean accuracy in each round, with a random effect of Dyad, communicative success increased as the mean semantic distance shrank between incorrect guesses and correct targets, $b = -0.21$, $t = -2.24$, $p = .033$. In other words, if a dyad's *incorrect* guesses were generally closer to the correct target meaning, then they also made more correct guesses overall (see Fig. 5).

Discussion

We investigated the emergence of structured semiotic systems for communicating about an entirely abstract domain, *time*. Despite the novelty of the signalling device, and the restricted range of possible signals, dyads established successful systems. Signal-meaning structure increased over time, with the emergence of systematic mappings between space and time. These mappings were often combined productively, suggesting compositionality. And with this increased structure came increased communicative success. Thus, structure emerged, participants used this structure when guessing, and this improved communication.

The presence of early, shared regularities and later, idiosyncratic structure sheds light on the role of individual cognitive biases, social coordination, and interaction history on the emergence of systematic mappings between space and time. The mapping between temporal duration and spatial extent, for instance, was established early in the first round and followed the same direction in all dyads (short=small). These results suggest that participants had shared, strong initial biases about the relation between spatial extent and temporal duration, perhaps due to innate intuitions, systematic polysemy in language, or systematic conflation of length and duration in our lived experience (Lakoff & Johnson, 1980; Walsh, 2003; Winter, Marghetis, & Matlock, 2015). In contrast, although almost every dyad eventually began to use location to distinguish past from future concepts, the specific strategy was more variable across dyads. This suggests that participants lacked strong, shared biases, and shared *interaction history* was thus more critical here. This finding also confirmed that our American participants did not have a strong initial bias for associating location or direction with past/future. The emerging structures of these semiotic systems reflect an interplay between individual biases and social coordination. We suspect similar dynamics were likely at work in the emergence of space-time mappings in natural language.

This combination of variability and universality mirrors regularities in human cognition and natural language. On the one hand, evidence from non-human animals and child development suggests that spatial extent and temporal duration are tightly linked, perhaps innately (for a review: Winter, Marghetis, & Matlock, 2015). On the other hand, for concepts other than magnitudes, there is considerable cross-cultural variability in how time and space are intertwined. For instance, while English associates the future with the space ahead of the body, the Aymara of Chile reverse this mapping, associating past with the space *behind*, and the Yupno of Papua New Guinea associate the future with *uphill* (Núñez & Cooperrider, 2013). Thus, the interaction between cognitive biases and social coordination during our communication game is a microcosm of a larger network of biases and pressures. These mechanisms must be considered together to account for the mix of universality and variability that we find around the world.

While the semiotic systems in our study began to capture the structure of the meaning space, no fully systematized language emerged. As we saw, some of the more similar meanings in the set (e.g. "tomorrow" *vs.* "day after") were still confused in the later rounds. What would be needed for these systems to develop ways to distinguish even these very similar sequence and deictic concepts? Our hypothesis is that these early-emerged patterns will evolve into more regular systems once they are transmitted across multiple generations of interacting users. Iterated learning studies have found increasing regularization when languages are transmitted over generations (e.g. Kirby et al., 2008). When a system is transmitted from generation to generation it adapts to become more learnable and more structured. We are currently conducting a follow-up study using *iterated* communication (Tamariz et al, 2012; Verhoef et al., 2015).

How specific are these results to the domains of time and space? On the one hand, space and time may have a privileged relation, tightly linked in thought, language, and gesture (Núñez & Cooperrider, 2013; Winter et al, 2015). On the other hand, the domain of time is not alone in relying on space for its conceptual and linguistic structure. Abstract domains as varied as number and morality make systematic use of spatial language (Lakoff and Johnson, 1980). For number, at least, there are also strong early biases to associate numerical magnitude with spatial extent. The interaction between cognitive biases and cultural processes has been identified as an important drive in the emergence of structured semiotic systems before. What the domain of space and time contributes is a clear identifiable distinction between parts of structure that appear to be more rooted in strong shared biases and parts that result from cultural evolution, all within one emerging system. These findings are likely generalizable to other such domains.

This study is limited by the extensive linguistic experience of the participants, who already had words in their native language (English) for the meanings to be communicated. This may have influenced their ability to create a new semiotic system. Indeed, the association between length and duration is reflected in English polysemy ("long time", "long stick"). However, as we saw, much of the new structure (e.g., associations between up/down and past/future) consisted of mappings that are absent entirely from English. Future research may explore the negotiation of novel semiotic systems for concepts that lack associated lexical items.

Conclusion

To explore the link between individual-level behaviors and population-level communication systems, consideration of different mechanisms is needed (Beckner et al, 2009). Here, we focused on the interaction between initial individual biases and cultural processes and how these may contribute to the emergence of space-time mappings. By foregrounding the interplay between such mechanisms that operate on disparate timescales, laboratory experiments can shed light on the commonalities and variety found in space-time mappings in languages around the world.

References

Beckner, C., Blythe, R., Bybee, J., Christiansen, M. H., Croft, W., Ellis, N. C., et al. (2009) Language is a complex adaptive system. *Language learning*, 59, 1-26.

Caldwell, C. A., & Smith, K. (2012). Cultural evolution and the perpetuation of arbitrary communicative conventions in experimental microsocieties. *PLoS ONE*, 7, e43807.

Christiansen, M. H. & Chater, N. (2008). Language as shaped by the brain. *BBS*, 31(5), 489–509.

Fay, N., Garrod., S., & Roberts, L. (2008). The Fitness and Functionality of Culturally Evolved Communication Systems. *Philosophical Transactions of the Royal Society B-Biological Sciences*, 363, 3553-3561.

Fusaroli, R., & Tylén, K. (2012). Carving language for social coordination: A dynamic approach. *Interaction Studies*, 13, 103–123.

Garrod, S., Fay, N., Lee, J., Oberlander, J., & MacLeod, T. (2007). Foundations of Representation: Where Might Graphical Symbol Systems Come From? *Cognitive Science*, 31(6), 961-987.

Gentner, D. (1983). Structure mapping: A theoretical framework for analogy. *Cognitive Science, 7,* 155-170.

Haspelmath, M. (1997). *From space to time.* Munich & Newcastle: Lincom Europa.

Hockett, C. (1960). The origin of speech. *Scientific American*, 203, 88–96.

Kirby, S., Cornish, H. & Smith, K. (2008) Cumulative cultural evolution in the laboratory: An experimental approach to the origins of structure in human language. *PNAS*. 105(31), 10681-10686

Kirby, S., Griffiths, T., & Smith, K. (2014). Iterated learning and the evolution of language. *Current Opinion in Neurobiology*, 28C, 108-114.

Lakoff, G., & Johnson, M. (1980). Metaphors we live by. Chicago, IL: University of Chicago Press.

Núñez, R. E., & Cooperrider, K. (2013). The tangle of space and time in human cognition. *TiCS*, 17, 220–229.

Scott-Phillips, T. & Kirby, S. (2010). Language evolution in the laboratory. *TiCS*, 14(9), 411–417.

Steels, L. (1997). The synthetic modeling of language origins. *Evolution of communication*, 1(1), 1–34.

Tamariz, M., Cornish, H., Roberts, S. & Kirby, S. (2012) The effect of generation turnover and interlocutor negotiation on linguistic structure. In *Proceedings of EVOLANG9*. World Scientific, (pp. 555-556).

Theisen, C., Oberlander, J. & Kirby, S. (2010) Systematicity and arbitrariness in novel communication systems. *Interaction Studies*, 11(1): 14-32.

Verhoef, T. (2012) The origins of duality of patterning in artificial whistled languages. *Language and Cognition*, 4(4), 357-380.

Verhoef, T., Roberts, S. G., Dingemanse, M. (2015) Emergence of systematic iconicity: Transmission, interaction and analogy. *37th Annual CogSci Conference* (pp. 2481-2486) Austin, TX: Cognitive Science Society.

Walsh, V. (2003). A theory of magnitude: Common cortical metrics of time, space and quantity. *TiCS*, 7, 483–488.

Winter, B., Marghetis, T., & Matlock, T. (2015). Of magnitudes and metaphors. *Cortex*, 64, 209-224.