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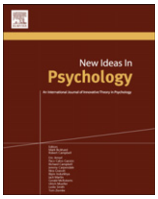

Perspective-taking in dialogue as self-organization under social constraints

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ABSTRACT

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Language
Perspective-taking
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We present a dynamical systems account of how simple social information influences perspective-taking. Our account is motivated by the notion that perspective-taking may obey common dynamic principles with perceptuomotor coupling. We turn to the prominent HKB dynamical model of motor coordination, drawing from basic principles of self-organization to describe how conversational perspective-taking unfolds in a low-dimensional attractor landscape. We begin by simulating experimental data taken from a simple instruction-following task, in which participants have different expectations about their interaction partner. By treating belief states as different values of a control parameter, we show that data generated by a basic dynamical process fits overall egocentric and other-centric response distributions, the time required for participants to enact a response on a trial-by-trial basis, and the action dynamics exhibited in individual trials. We end by discussing the theoretical significance of dynamics in dialog, arguing that high-level coordination such as perspective-taking may obey similar dynamics as perceptuomotor coordination, pointing to common principles of adaptivity and flexibility during dialog.

1. Introduction

Perspectives are a fundamental aspect of daily interaction. In order to be understood when speaking, or in order to understand someone who is speaking, it is often important to integrate attributions we might make about our conversation partner. If someone wanders up and asks in an accent of a non-native speaker, “Where is downtown Merced?” we may adjust how we articulate our instructions, in a way that is shaped by knowledge of this person. When a close friend asks, “How do I look in these pants?” our response may be shaped by knowledge of the person’s traits, their mood on that day, or the gravity of the event to be attended. Sometimes when we violate these principles of perspective-taking, consequences are dire; other times, they can be innocuous.

This process of integrating information about another human being with whom we are talking is one of our most heralded cognitive skills. However, an account of such perspective-taking skill has not been developed in emerging dynamical accounts of interpersonal coordination. Instead, the focus has been on the perceptual and motor channels and how they couple individuals. In experiments motivated by a dynamical systems account of interpersonal interaction, there is clear evidence that people spontaneously coordinate their movements during communicative tasks (Dittmann & Llewellyn, 1969; Fowler, Richardson, Marsh, & Shockley, 2008; Kendon, 1970; Shockley, Richardson, & Dale, 2009). The structure of this coordination indicates that people operate as a coupled system, whereby individual motor systems are reorganized

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into more efficient modes of adaptive responding (Riley, Richardson, Shockley, & Ramenzoni, 2011). These modes are better able to stabilize in the presence of perturbations and in transitioning between shared behavioral repertories. Moreover, in some domains, this alignment has been hypothesized to reflect coupled mental states that facilitate information transmission, as in promoting common frames of reference for language comprehension, and in establishing turn-taking rhythms that assist in word learning (Pereira, Smith, & Yu, 2008; Richardson & Dale, 2005).

Critical to this view of motor and cognitive coordination are the perceptuomotor channels that bind individuals into functional units. Cues such as eye gaze, acoustic patterns of speech, and the movements of another's hands and head, all constrain how behavior systematically unfolds in a social environment (Fowler et al., 2008; Richardson, Marsh, & Schmidt, 2005; Shockley, Santana, & Fowler, 2003). What remains unclear, however, is how the mere beliefs or knowledge about another, rather than observations of their actions, act to coordinate shared cognitive states. In numerous studies, it has been shown that assessments about abstract, other-oriented *attributes*, ranging from another's linguistic efficiency to their geographic region of residence, have immediate effects on how language users come to negotiate and share meaning (see Brennan, Galati, & Kuhlen, 2010 for a review). Put differently, the connection between interacting individuals is not always purely perceptuomotor; sometimes it is *attributional* or *informational*.

In the current work, we seek to bridge what might appear at first glance to be disparate research programs. Dynamical systems accounts typically operate within contexts where language users are physically co-present and bound by similar motor systems. Yet, communication still succeeds when all that links language users is informational content, such as in the extreme case of computer-mediated communication, to everyday conversations where the perceptuomotor cues are subsidiary to understanding what another is trying to say. Thus, to find a bridge, and to provide a more comprehensive account of meaning generation during interpersonal interactions, dynamical accounts must be extended to account for the effects of partner-specific knowledge in conversation.

To do so, we argue that attributional information serves the same function as perceptuomotor cues during communication. Instead of providing the means by which movement is coordinated, they act to constrain mutual understanding between language users. Thus, the attributes are a control parameter that influences perspective-taking during linguistic interpretations. This notion of control is analogously found in joint action tasks where perceptual affordances guide cooperative behavior. In Richardson, Marsh, and Baron (2007), people moving planks of wood have been shown to predictively switch from autonomous to cooperative action based on a relationship between each other's arm span and the length of the plank. In similar fashion, language users will take on a particular interpretative stance, that is more or less cooperative in establishing shared meaning, based on "affordances," or attributions, that are rapidly assimilated and reinforced throughout communicative interactions. These attributions act to warp comprehension processes from the start, influencing how individuals come to exhibit stable, yet flexible patterns of responding.

To relate this dynamical process to human response behavior in a linguistic task, we turn to a simple dynamical model of experimental data. This model is derived from a prominent mathematical model of bimanual motor coordination. Originally developed by Haken, Kelso, and Bunz (1985) (HKB) to capture phase transitions in what is called a "bistable attractor landscape" (explained further below), this model has been extended to a variety of domains, revealing widespread commonalities between perceptual, cognitive, and motor systems (e.g., Engstrom, Kelso, & Holroyd, 1996; Frank, Richardson, Lopresti-Goodman, & Turvey, 2009; Tuller, Case, Ding, & Kelso, 1994; van Rooij, Bongers, & Haselager, 2002; see Chemero, 2009; Schmidt & Turvey, 1995; for reviews). The value of this dynamical model is that it captures complex behaviors based on simple, unifying principles of behavioral change brought about by situated, environmental constraints.

In the HKB extension for our perspective-taking task, we follow a strategy that adheres to basic steps laid out in previous research (Beer, 2003; Raczaszek-Leonardi & Kelso, 2008). First, we need to find a tractable way of expressing the coupling between language users in a communicative task. This requires reducing the multiple sources of information involved in an interaction (i.e., system complexity) to a quantifiable and transparent outcome variable. By doing so, this simple behavioral variable can then be used to characterize cognitive processing in the interactive task. Second, we need to identify the parameters that constrain (or govern) how this cognitive process emerges or changes. Third, we must develop a version of the dynamic model under these constraints and show how its behavior maps onto human performance, thus providing a qualitative demonstration of the unfolding dynamics observed in that performance.

The human data we model is taken from a recently published study of Duran, Dale, and Kreuz (2011). In this task, participants were required to interpret verbal instructions from a seemingly real, but simulated partner who directed them to select an object on a computer screen. Occasionally, instructions could be ambiguous with respect to which object (e.g., one on the left, or the other on the right) should be selected. Although language users were not physically co-present, the spatial referent was ostensibly visible to both. Depending on attributional information available about their computer partner, participants either grounded interpretation from their own visual perspective (i.e., egocentric stance), or from the visual perspective of their partner (i.e., "other-centric" stance). In other words, an ambiguous description could be resolved as a selection indicating *perspective*: "choosing the object on *my* left" vs. "choosing the object on *their* left." In terms of our simulation strategy, these interpretative stances constitute behavioral outcomes captured with a one-dimensional variable. Obviously perspective-taking is based on a diverse range of requisite cognitive processes, but for current purposes, outcome is expressed on a single dimension: Which perspective is the participant taking? This low-dimensional characterization is in terms of egocentric vs. other-centric *response distributions* as indicating which stable perspective the participant is adopting. What constrains this perspective-taking dynamic? The attributions, as well as egocentric biases inherent in the processing task, dictate how participants decided on their responses, resulting in unique temporal patterns within and across trials. As we show, there is systematic congruence between the model's predicted behavior and human behavior, suggesting common principles of self-organization underlie motor coordination and physically decoupled, but *informationally-situated*, communication.

It should be noted that with the current dataset the scope of the communicative context is admittedly limited. As is often the case, trade-offs were made between ecological validity and experimental control. Nevertheless, the conditions of the study allow for convincingly real social interactions to occur. Indeed, many participants believed they were connected to an actual human being. Though simple, the task required participants to receive, interpret, and communicate information with a partner who, for all intents and purposes, was also socially receptive. As such, participants were actively considering partner attributes in forming their interpretations. Using attributes to guide perspective-taking can also be said for participants who knew their partner to be a simulation. There is a wealth of evidence suggesting that people orient to human–computer interactions in the same way as they do with human–human interactions (e.g., see Nass, Fogg, & Moon, 1996). However, the nature of the attributes will likely vary. When a partner is known to be simulated, certain allowances are extended that are not when a partner is assumed to be real. It is these differences that we exploit in the current demonstration.

In the sections that follow, we discuss the Duran et al. (2011) study in greater detail and present new results that offer up a challenge to a dynamical systems interpretation (Sections 3 and 4). We then describe one such dynamical model that can qualitatively capture the experimental results across various time scales (Sections 5 and 6). Although our primary goal is to extend dynamical systems accounts of interpersonal interaction, our approach also lends itself to another possible theoretical contribution not yet discussed. In the domain of pragmatics and communication there is an ongoing debate about the influence of attributional information on language comprehension. This debate centers on how much of meaning is mediated by conversational partners vs. the product of individual, egocentric interests. In the former, attributions are essential and seamlessly integrated into language processing; in the latter, attributions play a more secondary role. With the simulation presented in this paper, we provide additional support to the mediated claim. However, we also show that egocentric biases have a prominent role and are co-activated even when language users take an other-centric stance. Thus, before moving on with the simulation, we first provide additional background in order to substantiate our claim that a dynamical systems approach can uniquely inform, and potentially integrate, theories of dialog.

2. Process models of discourse

Conversation is seemingly easy, and even with people we have just met, a systematic back and forth exchange can rapidly unfold. Despite a speech stream that is often littered with ambiguities, hesitations, and disfluencies, people come to align on shared conceptual understanding (Clark & Brennan, 1991; Schober & Brennan, 2003). A major question is how much of this emergent meaning, or *sense-making*, is due to language users' *individual* cognitive processes vs. that of *collaborative* processes shared between language users? In individualistic accounts, the cognitive mechanisms for sense-making are based on the minimization of processing demands for the speaker alone, with consideration of a partner's processing needs occurring only when absolutely necessary, or when such consideration can be done without overburdening demands on executive function (Horton & Gerrig, 2005; Keysar, Barr, & Horton, 1998). Thus, language users primarily take an *egocentric* stance in comprehension and production, where partner attributes, in terms of their unique beliefs, histories, and knowledge, are not necessary for successful communication (Shintel & Keysar, 2009). Instead, one's own mental states can be used as a proxy for what another might know; and given that the conversational context is usually shared, and knowledge is likely to overlap, linguistic behavior only appears to be adapted for another (Dell & Brown, 1991; Epley, Keysar, Van Boven, & Gilovich, 2004; Keysar et al., 1998). For example, when speakers refer to objects with a conversational partner, it is usually the case that initial mentions of objects are articulated much clearer than subsequent mentions. Although it may appear that such attenuation occurs because understanding has been established with a partner early on and no longer needed downstream, the alternative explanation is that participants are simply minimizing their own cognitive effort (Bard et al., 2000).

This egocentric view is consistent with other mechanistic accounts of conversation, including the prominent interactive alignment model where cross-partner priming carries the explanatory weight for cognitive convergence (Pickering & Garrod, 2004). The appeal of this account is that priming is a cognitively inexpensive and fast-acting mechanism that is insulated from attributional influences. The interactive alignment model has been compared elsewhere to the coupled dynamical systems perspective, given that conceptual convergence in both models can be scaled up from lower-level motor coordination. However, the comparison comes with some major caveats (see Shockley et al., 2009). One of these is what qualifies as a constraint on coordination? From a dynamical systems perspective, sense-making in communication is a participatory act where meaning is created through the reciprocity of real–time interaction (De Jaegher, Di Paolo, & Gallagher, 2010; Marsh, Richardson, & Schmidt, 2009; Thelen, Smith, Lewkowicz, & Lickliter, 1994). Thus, partner attributes, which are very much a part of the contextual environment, can be quickly assimilated through social interaction, with this information acting to constrain sense-making possibilities. Attributions of belief are just another source of information that is automatically integrated and acts to guide individuals into convergent states of understanding.

This view resonates with the collaborative process models of discourse that argue language users are "plugged into" an interactive social context, where *a priori* and evolving beliefs about a conversational partner—in terms

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of what they might think, see, know, or want—have immediate effects on processing (Brennan, 2004; Hanna & Tanenhaus, 2004). This partner information can range from global cues, as in characteristics inherent to who the partner is (such as gender), to local cues that emerge throughout the course of the conversation (such as discovering a shared interest in wine tasting). Often, these cues can also be reduced to two alternatives, as in whether a conversational partner is very young or not, or whether a partner can see or cannot see objects being discussed (Brown-Schmidt, Gunlogson, & Tanenhaus, 2008; Newman-Norlund et al., 2009). As Brennan and Hanna (2009) note, such partner attributions act as simple "one-bits" of information that transform sense-making processes from individualistic to collaborative orientations, and do so without inflicting increased cognitive demands on language users.

It is important to note, however, that the above claims do not negate evidence that people sometimes behave egocentrically. It is still quite possible that the saliency of attributional information may be insufficient to elicit other-centric behavior, and may even push language users toward egocentrism. However, rather than taking an "either/or" approach, we suggest that both egocentric and other-centric response biases are simultaneously activated, with biases competing for expression. Based on the graded saliency of the attributional information, each response type will be probabilistically more or less stable, and will exhibit a unique time course in reaching stabilization.

The simulation presented here, based on the HKB model, is capable of capturing the distributional and temporal patterns that arise from competing activations. In doing so, it provides a *complementary* account of perspective-taking that integrates both egocentric and other-centric biases within a single dynamical framework.

3. Perspective-taking during an online communication task

In this section, we turn to the experimental data in which the human response patterns are described, borrowing from the recently published work of Duran et al. (2011). In this study, the goal was to show how spatial perspective-taking in a communicative task is modulated by belief attributions. Participants were told to respond to the instructions of a simulated partner who asked for one of two folder icons displayed on a tabletop graphic. The instructions were ambiguous in that they could be interpreted from the perspective of the instruction-giver or from the participant's own perspective. This was manipulated through the orientation of the folders and the position of the participant and instruction-giver around the tabletop. For example, if a participant and her partner are at opposite sides of the table, with the folders laid out side-by-side, the instruction, "Give me the folder on the right" would be ambiguous. The participant has the option of interpreting the folder as being on her right (an egocentric perspective), or on her left (i.e., the partner's right; an other-centric perspective). Across a series of 40 trials, the partner's verbal instructions ("folder on/in the…" "right," "left," "front," and "back") were strategically paired with particular folder/partner location combinations to create 20 shared-perspective and 20 ambiguous (or critical) trials (see Fig. 1 for a step-by-step walk-through of an ambiguous trial).

A general finding was that during the critical trials a large proportion of participants were willing to take the more cognitively challenging other-centric perspective, as evidenced by increased processing time corresponding to mental transformations of the visual array to "see" the table from the partner's point of view. Interestingly, even when no mental rotation was required because the requested object's position was consistent with both ego- and other-centric perspectives, participants who were responding other-centrically still took longer to respond. This suggests that using the other as an external frame of reference was also present in shared-perspective trials, revealing a complete mode switch to other-centric adaptive responding.

The set up of the task also allowed insights into why participants probabilistically chose other-centric over egocentric interpretations. As mentioned earlier, participants knew that instructions were recorded, albeit in a context that was designed to be interpreted as naturalistic (e.g., instructions were delivered in a conversational tone by a male speaker and trials proceeded as turn-taking exchanges). Furthermore, there was no explicit feedback given by the speaker to disambiguate the "correct" or intended response. Taken together, these factors could lead to high rates of egocentric responding, and indeed for some, egocentric responding was the primary response. However, given the high rates of other-centric responding, an explanation for these participants is still required. Duran et al.'s (2011) interpretation is based on the principle of collaborative least effort (Clark & Wilkes-Gibbs, 1986, 1992), whereby people approach interactions with a general orientation toward collaboration. A primary goal during dialog is to work towards reducing each other's efforts in comprehension and towards a shared understanding (Clark & Krych, 2004). Therefore, if a participant believes their partner to be incapable or hindered in their ability to cooperate—for example, the partner is a non-native speaker (Bortfeld & Brennan, 1997)—then the participant is likely to invest greater effort and respond other-centrically.[1] Absent any such attributions, the distribution of egocentric and other-centric interpretations, across participants, is likely to be more evenly balanced, or even weighted toward egocentrism. This latter possibility is supported by an assumption of egocentric primacy in

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[1] We argue that this principle still applies for contexts like the one used here, where the interactive context is obviously impoverished. Perceived limitations of a seemingly real communicative partner, whether the partner is actually real or not, is a sufficient cause for exerting greater effort (i.e., acting "other-centrically"). This same effect has been found in a variety of research domains, from human–computer interaction (Branigan et al., 2011) to spatial referential tasks (Schober, 1993). However, we do acknowledge that the principle was first observed with explicitly collaborative interactions. Perhaps here, and in Duran et al. (2011), an appropriate amendment would be a principle of "expectations for required effort." In that, when interacting with a simulated partner who cannot provide explicit feedback, participants expect to exert greater effort because they are uncertain about the competency, ability, or "knowledge" of the anthropomorphized simulated partner.

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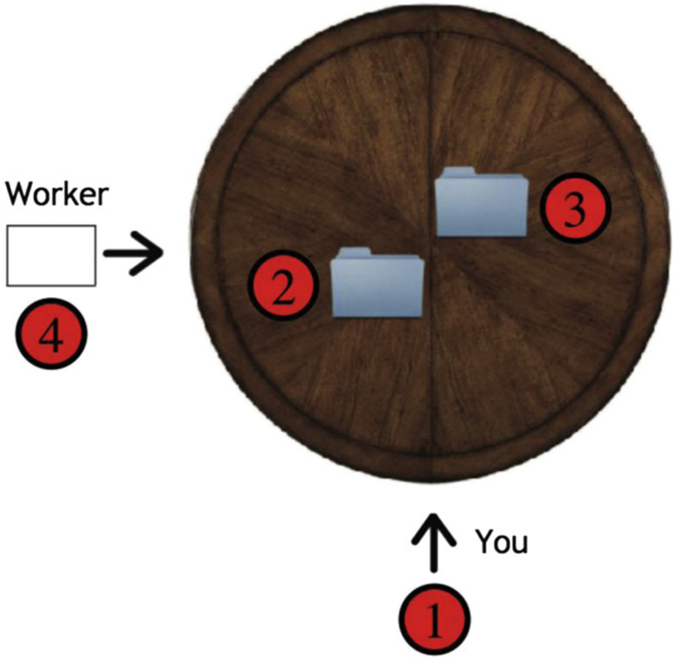

Fig. 1. A trial began by automatically placing a participant's mouse cursor underneath an empty simulated table (Position 1). Verbal instructions were then given by a simulated partner who directed the participant to select one of the folders placed on the tabletop. At this time, the participant pressed a "GO" button (also located at the bottom of the screen), and the folders and the partner's location appeared. Folders were arranged diagonally (Position 2 and 3), vertically, or horizontally. The participant was to then drag the selected folder to the simulated partner who was located somewhere around the table, either at the other sides of the table (as shown in Position 4). Its use does not affect the current results. Based on the layout in this ambiguous example, if the participant heard, "Give me the folder on the right," and selected the folder at Position 3, he or she would have interpreted the instructions egocentrically. However, if the participant selected the folder at Position 2, he or she would have interpreted the instructions other-centrically. As participants were moving toward and selecting a folder, we were rapidly sampling the *x*,*y* coordinates of their mouse cursor at every 25 ms (a sampling rate of 40 Hz). Response time analyses are based on the time between pressing "GO"' and selecting an initial folder. A version of the game can be accessed at: cognactive.org/perspectiveTask. Also note: the 'Worker' label above corresponds to one of the identities assigned to the simulated partner and was used to address a separate research question.

spatial and reasoning tasks (Nickerson, 1999; Shelton & McNamara, 1997; Wang & Spelke, 2000).

To demonstrate these effects, Duran et al. (2011) provided subtle instructional manipulations across three conditions that were designed to influence the inferences participants made about their partner. One of these manipulations was to present a cover story that convinced a majority of participants that the simulated partner was indeed real. This was possible because all interactions took place over a crowd-sourcing service called "Amazon Mechanical Turk." The service works by having participants log-in from across the United States to complete simple tasks for monetary compensation (see Munro et al., 2010 for further details). Because there is a very high likelihood that multiple users are using this service simultaneously, Duran et al. told participants that they would be "connected" to a fellow user who would act as an instruction-giver, following the same format of the interactive task described above and in Fig. 1. In a separate condition, all pretense was eliminated and participants knew that the voice giving the instructions was that of a simulation. Duran et al. then compared perspective-taking behavior for participants who believed their partner to be real vs. those that did not, with the assumption that rates of other-centric responding would be higher when one's partner was simulated (i.e., a partner incapable of cooperating) than when the partner was considered real (i.e., a partner capable of cooperating). As with previous research that has found enhanced perspective-taking with a simulated partner (e.g., Branigan, Pickering, Pearson, McLean, & Brown, 2011), support for our hypothesized pattern of results was also found. Thus a key attribution related to the task, "there is someone on the other end," shaped the response strategies of participants.[2] This simple attributional factor is one we focus on in the next sections.

4. Results: human

Before we turn to our model and theoretical discussion, we sought detailed experimental results to test our

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[2] An alternative explanation is that given the use of a simulated partner, participants are not making attributions about their partner, but rather, based on how the experimenter may want them to respond. However, given that the current findings are consistent with previous research, this explanation seems unlikely. It should also be noted that participants were allowed to provide post hoc "introspective" comments about their experience with the task. Although not explicitly analyzed, no participant made any statement that would suggest they were considering the experimenter's perspective.

proposed approach. In what follows, we present a somewhat detailed reanalysis of the Duran et al. (2011) dataset by focusing on data derived from the studies involving *seemingly real* and *knowingly simulated* partners. Three sets of results are presented. We first replicate the response distribution found in Duran et al., albeit with combined data from Studies 1 and 3 taken from the original publication. We then home in on the action dynamics in the computer-mouse movements, exploring differences between the seemingly real and knowingly simulated conditions (hereafter referred to as "Believe Real" and "Believe Simulated" attributional conditions). Taken together, the collective pattern of results taps into the dynamics of perspective-taking under different attributional contexts. As we will show, they are also uniformly captured by a model operating on simple principles of interactive change.

4.1. Endpoint distributions: human

There were 76 participants in the Believe Real condition, and 85 participants in Believe Simulated. Across these two conditions, participants were identified as being consistently other-centric, egocentric, or a mixture of these two perspective-taking types. This assignment was based on the proportion of egocentric responding across the 20 ambiguous trials, with a score over 70% resulting in an egocentric identification, and a score below 30% resulting in an other-centric identification. A score between 30% and 70% was mixed. The percentage of participants who were classified into one of these three categories is reported in Fig. 2.

For Believe Simulated, there was an equivalent bias in other-centric and egocentric responding, with a slight, although statistically insignificant advantage for other-centric responding (other-centric: 52%, egocentric: 38%). For believe real, the opposite pattern was shown, with a larger number of egocentric responders (64%) than other-centric responders (28%), *chi-square* $= 13.59$, $p < .001$. In comparing the change of other-centric responding between conditions, it was found that in Believe Simulated, where the partner cannot contribute to shared understanding, there was a much higher incidence of other-centric responders than in Believe Real, where the partner is a more viable contributor. Thus, there was an increase of 24% in other-centric responding across conditions, *chi-square* $= 6.87$, $p = .009$. These results support the notion that participants are more willing to take on greater processing demands when there is a perceivable limitation of their communicative partner. It also weakens the argument for egocentric primacy, which might assume that when there is no partner, the only available perspective is one's own. This does not appear to be the case.

4.2. Response times: human

In this reanalysis of the original dataset, we evaluated the change in response time[3] across ambiguous trials for the other-centric and egocentric responders. The statistical analyses reported here were conducted with mixed-effects models that compared responder type (other-centric vs. egocentric) and condition (Believe Real vs. Believe Simulated) as fixed factors. We also included random factors of subject and item.[4] It should also be noted that the generated p-values were computed with 10,000 Monte Carlo Markov Chain simulations (see Baayen, Davidson, & Bates, 2008). We report these significance values along with unstandardized effect estimates for the corresponding effects.

For the overall model, there was a statistically significant main effect for responder type $B = 301$ ms, $p < .001$; a significant main effect for condition, $B = 362.90$ ms, $p < .001$; and a significant interaction between responder type and condition, $B = 244.10$, $p = .041$. This latter result suggests response time differences between other- and ego-centric responders that were modulated by condition. To examine these differences in greater detail, we ran follow-up tests within each condition, adding a factor of trial number to evaluate whether response times between other- and ego-centric participants decreased at unique rates.

For Believe Simulated, there was a main effect for responder type, with mean response time for other-centric responders significantly higher than the mean response time for egocentric responders, $B = 481.62$ ms, $p < .001$ (see Fig. 3). There was also an interaction between rate of decrease and responder type $B = 7.85$, $p = .005$, such that for other-centric responders, the average rate of decrease was 25 ms (Fig. 3, black solid line), $p < .001$, whereas for egocentric responders the rate of decrease was 17 ms (Fig. 3, grey solid line), $p < .001$.

For Believe Real, the main effect for responder type was also statistically significant, with other-centric responders having higher response time than egocentric responders, $B = 787.09$ ms, $p < .001$ (see Fig. 3). And again, there was a statistically significant interaction with rate of decrease, $B = 9.08$, $p = .004$. For other-centric responders, the average rate of decrease was 22 ms (Fig. 3; black solid line), $p < .001$, whereas for egocentric responders the rate of decrease was 13 ms (Fig. 3; grey solid line), $p < .001$.

Next, we ran follow-up tests within each response type, comparing response times between Believe Simulated and Believe Real. For other-centric responders, they were 402 ms slower, on average, in Believe Real compared to Believe Simulated, $p < .001$ (Fig. 3; black dashed lines). There were no differences in rate of decrease (Fig. 3; black solid lines). For egocentric responders, there were no statistically significant differences for mean response time, nor were there any differences in rate of decrease.

The general pattern here is that it takes longer to respond other-centrically, with response times decreasing across trials. And though egocentric responses were faster overall, they also exhibit a similar downward trend. In comparing other-centric responses across conditions, response times were slowest in the Believe Real condition. This latter result suggests that it is more difficult to respond other-centrically in Believe Real compared to

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[3] For response time, we collapsed over partner positions at the various locations around the table at 0, 90, and 180 degrees of rotation from the participant's fixed location.

[4] Item corresponds to the four orientations of the folder configuration.

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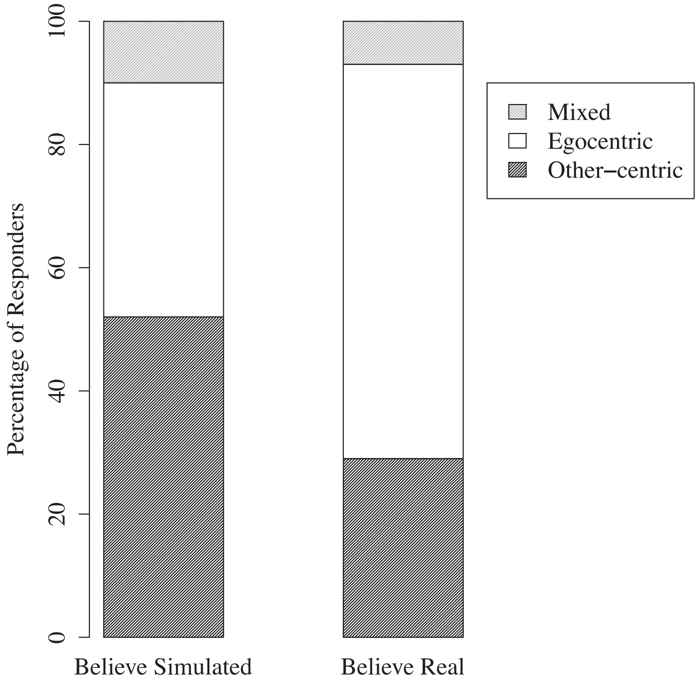

Fig. 2. The end point distributions of other-centric, egocentric, and mixed responders. When participants believed they were interacting with a simulated partner, their rate of other-centric responding was significantly higher than when they believed they were interacting with a real partner. The reason, we argue, is the principle of least collaborative effort elicited by belief attributions.

Believe Simulated. Given that the attributional constraints in Believe Simulated were more conducive to other-centric perspective-taking, facilitated responding should be expected. In the following analysis, we explore the underlying mechanisms that bring about this facilitation by examining competition effects that are undetectable with reaction time measures alone. Rather than collapsing potentially interesting moment-by-moment dynamics to a single time point, as reaction time measures do, we assess response movements in a more detailed spatiotemporal analysis.

4.3. *Response competition: human*

Drawing from a continuous dynamics view of the mind, mental activity unfolds across overlapping, and partially activated “attractor states” (Spivey & Dale, 2006). In the current task, these attractor states are thought to

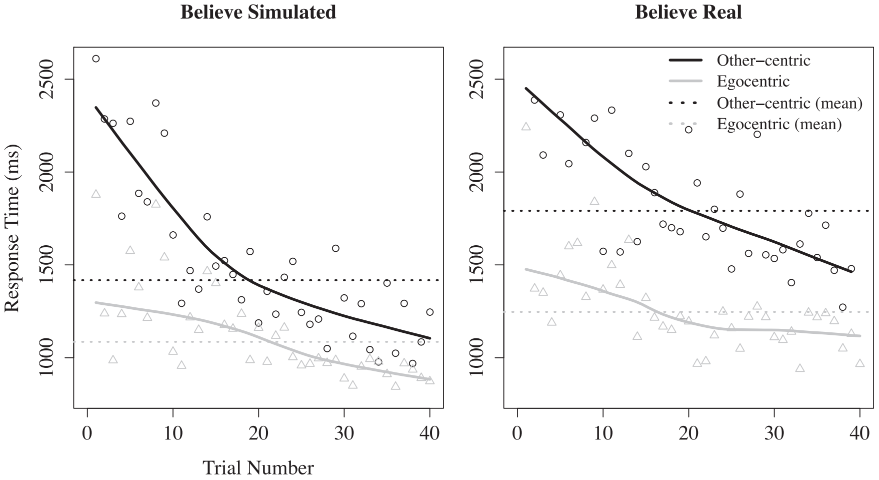

Fig. 3. The response times for other-centric and egocentric responders over trials. The slowest response times are for other-centric responders in the Believe Real condition.

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correspond to the egocentric and other-centric alternatives inherent in the response choice, and together they generate ongoing competition that is resolved during the time course of the decision. This activation is modulated by contextually situated sources of input, such that the egocentric attractor is likely to be reduced by the presence of stronger attributions that favor the other-centric perspective (as in the case of the Believe Simulated condition). Thus, we should find evidence for a weaker egocentric attractor during other-centric responses in Believe Simulated compared to Believe Real.

To identify attractor competition and modulation, we performed a curvature analysis on the mouse movements recorded during response selection. As shown in Fig. 1, the folder stimuli for each trial corresponds to a "visual world," which typically involves the simultaneous presentation of target and competitor choices in opposite regions of a response space (Spivey, Grosjean, & Knoblich, 2005). During ambiguous trials, the folder that is selected is considered the target, and because we are only evaluating other-centric responders, the target is always the other-centric option. The remaining folder constitutes a competitor that corresponds to the egocentric option. What we are most interested in are the competition effects elicited by the target and distractor folders as the arm moves en route to the other-centric target. In previous studies, these movements have been characterized by graded spatial arcs toward the competitor attractor (here, the egocentric response), suggesting that multiple interpretations are activated and cascade into the motor system (Duran, Dale, & McNamara, 2010; McKinstry, Dale, & Spivey, 2008).

We only examined mouse movement trajectories where folders were laid out side-by-side, thus ignoring folders in a stacked, vertical configuration. These trajectories were then interpolated to 101 time steps. At each time step, we recorded the average x,y coordinate trajectory position for each of the 76 subjects in the Believe Real condition, and for the 85 subjects in Believe Simulated.[5] Using an independent-samples *t*-test, we compared these average positions to determine whether there were statistically significant differences between conditions. This step was repeated at each time step to generate 101 *p*-value results. Based on previous bootstrap simulations, sequences of 8 or more contiguous *p*-values below the .05 criteria indicate significant divergence (see Dale, Kehoe, & Spivey, 2007). In our current dataset, we found evidence for 24 divergent time steps, between the 20th and 44th steps (Fig. 4). Importantly, the other-centric responses in the Believe Simulated, compared to Believe Real, appeared to be less influenced by an egocentric competitor. This result suggests modulation of competitor attractor strength as a function of attributional saliency.

4.4. Summary

The analyses present clear response patterns that result from a simple manipulation in the saliency of partner attributions. These attributions were in the form of whether a communicative partner was thought to be real or simulated. When simulated, other-centric responding was shown to be facilitated in three key ways: (a) the likelihood for other-centrism increased, (b) responses were faster within and across trials, and (c) decreased competition from an egocentric attractor. It is important to note that this shows behavioral change at three scales: the response distribution, the response time, and the response dynamics. We turn now to a dynamical systems simulation that qualitatively captures these general patterns by treating the attributional factors as control parameters on a low-dimensional attractor landscape of partly stable perspective-taking modes. By setting the parameters of the model to fit one of these levels (response distribution), the model has the surprising property of being consistent with the other two levels without further modification.

5. Modeling ego- and other-centric responses

The HKB model was originally developed to explain a core experimental finding in bimanual motor coordination (Kelso, 1981). In this early experiment, motor movement oscillations were shown to spontaneously transition from stable to unstable spatiotemporal patterns in response to simple environmental demands. Based on the HKB model, this process was interpreted as an example of how complex behaviors self-organize over time, with responses unfolding within a low-dimensional attractor landscape (Kelso, 1995). A primary strength of the model has been its ability to capture core principles of bistable dynamics with a minimal set of mechanistic commitments. For this reason, variations of the basic HKB model have been widely applied to a variety of perceptuomotor and cognitive tasks. In the current approach, we borrow from one prominent version of a bistable system used to model perceptual categorization in speech perception (Tuller et al., 1994). This study examined how the perceptual system converges on stable interpretations of speech sounds as a function of continuous variation in a single acoustic control parameter (e.g., hearing "say" or "stay" as the pause duration between the initial fricative and syllable in the word "say" was incrementally increased or decreased). The process by which stability and change emerged was shown to adhere to the same dynamics found in biomechanical coordination, including increased instabilities that mark the onset of interpretative transitions, and current state behavior that is highly dependent on prior response states—both hallmarks of self-organization.

We too are concerned with the temporal evolution of interpretation, but with particular focus on how attributional, information-based constraints guide *perspective-taking dynamics*. Our main point of departure, as we

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[5] The shape of the averaged trajectories is not the illusory result of combining trajectories of different dynamics, that is, trajectories whose shapes are bimodally distributed. Rather, unimodal distributions were found by taking the area under the curve (from a hypothesized straight line plotted from the initial and final *x*,*y* trajectory coordinates) and converting the resulting values to *z*-scores. Two tests of unimodality, the bimodal coefficient (Darlington, 1970) and Hartigan's Dip Test (Hartigan & Hartigan, 1985), were then conducted on pooled and individual-level data for all conditions. All analyses provide statistically significant support for unimodality.

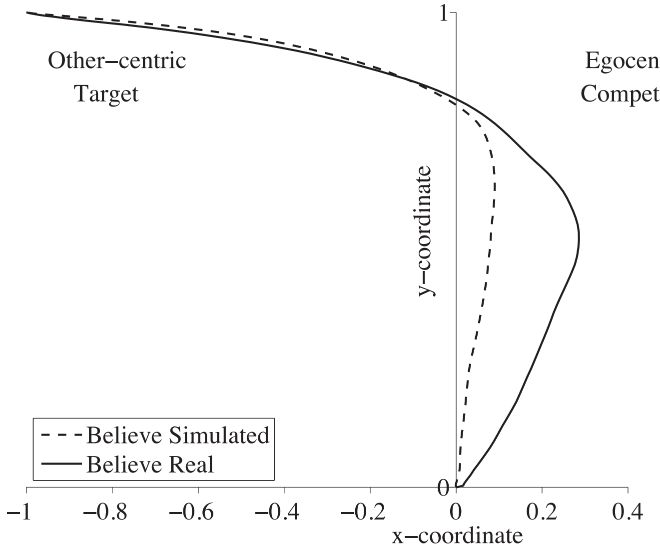

Fig. 4. Time-normalized trajectories for other-centric responders. There is decreased competition toward the egocentric response option for participants who believed they were interacting with a simulated partner (Believe Simulated) than with a real partner (Believe Real).

explain below, is that instead of sequentially varying a control parameter to evaluate dynamic behavior, we start with default values that correspond to bistable states of other-centric or egocentric interpretations. Importantly, this is akin to the “one-bit” interpretation of attributions described by Brennan et al. (2010). We then evaluate nonlinear response resolution at the level of an individual trial, and based on the outcome, the control parameter is allowed to vary over time. In this way, we can capture both global characteristics of stability in response choice, as well as the competition effects that influence the moment-by-moment processes involved in response execution.

At the core of the HKB model used here and in Tuller et al. (1994) is a simple mathematical function that defines a bistable response landscape. Stable states are geometrically represented by attractor basins (i.e., potential wells) that vary in steepness and direction. The particular shape of each basin corresponds to the likelihood and speed in which the system will settle into a particular response, with deeper and steeper basins indicating a stronger pull and therefore more rapid stabilization. In our model, the two possible response outcomes are other-centric or egocentric orientations to linguistic interpretations (see Fig. 5). This dynamical landscape can be expressed as the potential function

$$V(x) = kx - \frac{x^2}{2} + \frac{x^4}{4} \tag{1}$$

where a range of x values (e.g., $[-2.5,2.5]$) corresponds to the state space in which the system exists, and k a control parameter that specifies the steepness and direction of the basins. The potential function is derived from a solution of motion that depicts the system in action. This movement is captured in x,y space by

$$x_{t+1} = x_t + \left(-k_t + x_t - x_t^3\right) + \xi, \tag{2}$$

$$y_{t+1} = kx_t - \left(\frac{x_t^2}{2} + \frac{x_t^4}{4}\right), \tag{3}$$

where iterated changes in x move the system into an attractor basin, set by k, during the time course of a single trial. In this way, activation accumulates over time until an equilibrium criterion threshold is reached (see Table 1), much like the basic diffusion process used in two-choice decision tasks (e.g., Ratcliff, Van Zandt, & McKoon, 1999). The threshold is set high enough to allow sufficient stabilization, which provides an approximation of response time for decision choice. Depending on the initial conditions, where $x_{t=0}$, the system’s behavior is biased toward the attractor basin of closest proximity (Fig. 5; white circle). These initial biases are transitory and can be reinforced or abated by the values of the k control parameter, as well as a subtle noise signal, ξ, that may cause brief fluctuations around the saddle point (equidistant between wells), capturing initial indecision when the model first faces the task.

The model also exhibits variability in attractor choice and descent rate across trials. To capture these outcomes, once an interpretation has been made, the control parameter k is incremented,

$$k_{t+1} = k_t + \delta, \tag{4}$$

by δ from trial to trial in response to one choice or another (e.g., descending on the left causes k to bias the system towards future leftward responses). The attractor landscape is therefore in a state of flux, with trial-by-trial change in k reflecting a gradual commitment of strategy that participants tend to generally exhibit in egocentric and other-centric perspective-taking tasks (Carlson, 1999).

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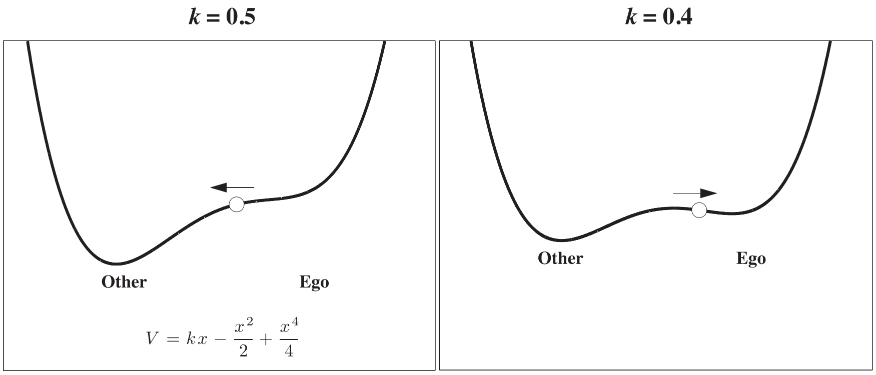

Fig. 5. Attractor basin landscapes with “Other” and “Ego” attractor wells. The shape of the landscape specified by control parameter, k, with initial conditions at white circle location. For the Believe Simulated condition ($k = 0.5$), the *a priori* attributions are hypothesized to increase the likelihood of other-centric responding relative to the Believe Real condition ($k = 0.4$). In addition, the ego-biased initial conditions in Believe Simulated are shifted closer to the saddle point, whereas for Believe Real the shift is away from the saddle point (denoted by black arrows).

In applying this model to the current task conditions, the values for the model parameters must be set by drawing on some underlying assumptions about the psychological processes involved (see Table 1). As discussed earlier, language interpretation during interactive communication is a shared activity in which social attributions act to constrain perspective-taking behavior. Constraint saliency will vary given contextual demands, probabilistically warping the likelihood of other-centric interpretations. In our experimental results, we provided evidence for this probabilistic shift as a function of manipulating a single source of attributional information. In terms of attractor basins, the condition in which “other-centrism” is more likely to occur will also exhibit a deeper and more stable well. We depict these landscapes in Fig. 5, where the control parameter k is adjusted accordingly. Importantly, the depth of the egocentric attractor lessens with higher k and increases with lower k, indicating an inverse relationship between the “pull” of other- and egocentric response interpretations. In other words, as one gets stronger, the other gets weaker.

We also set the initial conditions in this model by assuming that there is an immediate, although transitory, bias toward egocentric interpretations (akin to the claims of Epley et al., 2004). This bias is likely automatic, and is the result of a perceptual system that processes the world from a first-person perspective (Tversky & Hard, 2009). Thus, the parameter settings for the initial conditions will always start within the egocentric attractor, but will vary on where in the attractor they are placed. Depending on the attributional information, the initial conditions might be closer or further from the saddle point (and thus vary in terms of biasing strength). In this way, the initial condition settings are yoked with the control parameter settings; for example, with increases in k (attributions favoring other-centrism), an initial egocentric bias is weakened.

All additional parameters in the model (e.g., noise, threshold, and update rate) have fixed values and are equivalent across conditions. These values are reported in Table 1. Although this set-up is simple, it validates an important notion that easily observable parameters in a dynamical systems model, intuitively linked to theoretical

Table 1
Between condition values for default model parameter settings, the computational function of each parameter, and a general description of parameter role.

Parameter	Computational function	Parameter values		General description
		Believe simulated	Believe real	
k	Control parameter	.5	.4	Attributional strength that defines shape of the attractor landscape; updated on a trial-by-trial basis. Corresponds to “other-centric” activation.
$x_{t=0}$	Initial conditions	.2	.4	Initial egocentric bias for each trial; updated on a trial-by-trial basis.
δ	Activation update rate	.4	.4	Reshapes attractor landscape; updates value of control parameter (fixed). Biases system’s future responses based on previous choice.
Threshold	Criterion threshold	−3 or 3	−3 or 3	Activation criteria for response; negative corresponds to other, positive to ego (fixed). Allows sufficient activation for choice selection.
ξ	Noise	$\mu = 0$, $\sigma = .3$	$\mu = 0$, $\sigma = .3$	Gaussian distributed random error introduced across iterations (fixed). Causes brief fluctuations around saddle point; captures initial indecision.

assumptions, can account for a wide range of patterns in human response behavior. Setting parameters in this way, to develop qualitative explorations of behavior, is common in dynamical systems modeling and outlines of this strategy can be found in, for example, Gottman, Murray, Swanson, Tyson, and Swanson (2005).

6. Simulated patterns of behavior

We follow the same order of analyses reported in Section 4. We begin by simulating the behavior of 100 participants across 20 trials (corresponding to the 20 ambiguous trials seen by participants), using the parameter values in Table 1. These parameters represent the hypothesized processing constraints for participants in the Believe Real and Believe Simulated conditions. For each trial, the final response choice was recorded, as well as the number of iteration cycles required for activation to accumulate before reaching the response threshold. The number of iterations was used as a proxy for response time. Additionally, the activation values updated at each iteration were used to mimic human mouse movement trajectories.

It should be noted that the simulation results below are based on what can be considered a “phenomenological” model (see Di Paolo, Rohde & Iizuka, 2008; van Geert, 2000; for related approaches). The model fits the surface features of the human data. The goal was not to engage in detailed data fitting, but to show qualitative mappings between human and model response patterns. These mappings provide a proof of concept that aims to bridge a dynamical systems approach with pragmatic models of language comprehension. We should note, however, that this qualitative fit is not trivial. As we show below, the model, under these same fixed control parameter conditions, simultaneously exemplifies patterns of data along three behavioral scales: endpoint distributions, response-time characteristics, and response dynamics and competition patterns.

6.1. Endpoint distributions: model

We first identified other-centric and egocentric simulated participants who consistently responded with either perspective type (at least 70% of the trials), with inconsistent responders labeled mixed. The response distributions are shown in Fig. 6. As with the human data, there is a greater percentage of other-centric responders in the Believe Simulated compared to the Believe Real conditions. This distribution occurs because of weaker initial egocentric biases, and an initial and evolving attractor landscape that favors the deepening of the other-centric well (instantiated by the control parameter).

It is also important to note the presence of bi-stability within conditions here and in the human data. Even though the initial settings for all parameter values are identical, both egocentric and other-centric outcomes are possible given the nonlinear mechanisms that guide the system over time.

6.2. Response times: model

The response times for simulated participants also shows similar patterns with the human data. In both conditions, there is separation between the other-centric and egocentric responders, with the other-centric responses taking longer to reach a decision threshold (Fig. 7). These

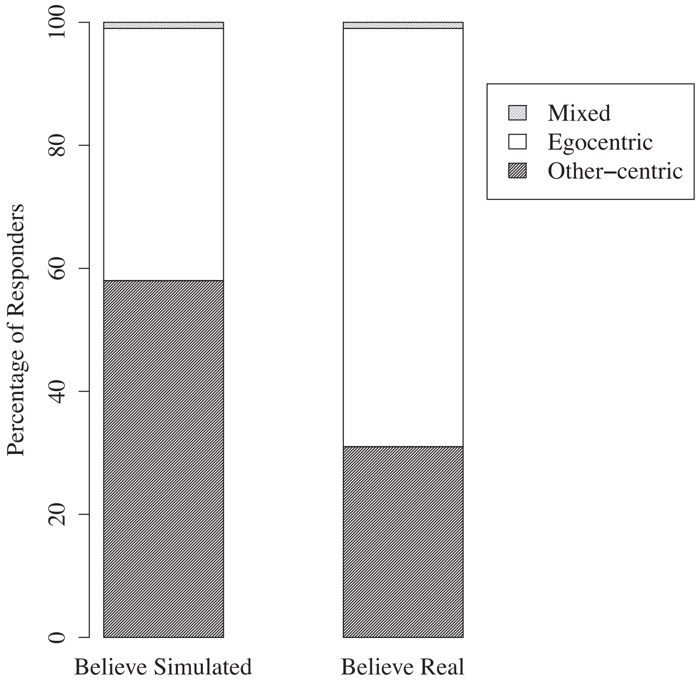

Fig. 6. Model end point distributions of response choice.

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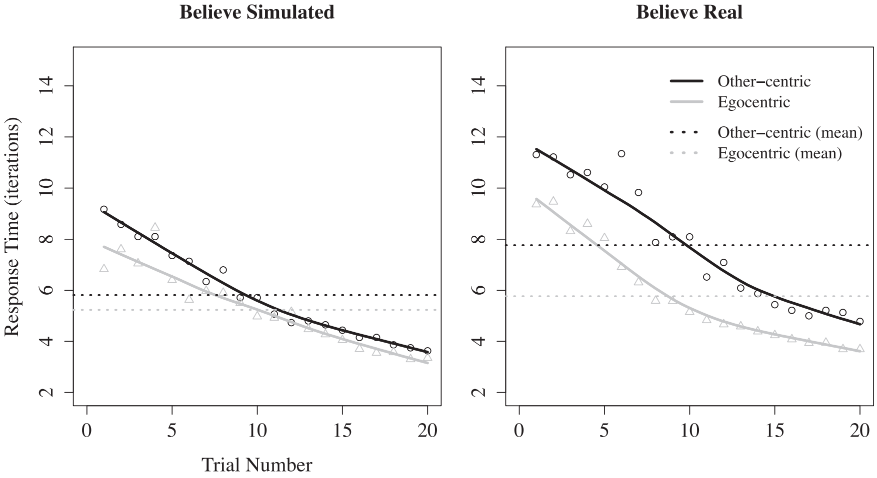

Fig. 7. Model response times (e.g., number of iterations to reach threshold) decreasing across trials, with the slowest response times for other-centric in the Believe Real condition.

slower response times are due to competition introduced by initial conditions that are biased toward the egocentric attractor. As was evident in the human data, this bias weakens over the course of sustained interaction marked by trial progression, and is caused by the updating of the control parameter (i.e., attributional saliency) that deepens the other-centric wells.

The egocentric responders also exhibit a downward slope indicating increasingly faster trials. This was also true for the human data. However, in both human and model results, there do not appear to be any differences between the Believe Real and Believe Simulated conditions, suggesting practice effects that are unaffected by the varying partner attributions across experimental conditions. In contrast, for other-centric responders, those in the Believe Simulated condition appear to have much faster response times than the Believe Real condition, where attributional information had a modulating effect. The response facilitation in Believe Simulated is due to settings of the control parameter and initial conditions that allow a stronger pull toward an other-centric attractor and simultaneous reduction of competition from the egocentric attractor. This is explored further in the next analysis.

6.3. *Response competition: model*

During each trial, the model's response behavior "moves" through its continuum as it settles into a response attractor. Given the competing influences of both other- and egocentric attractors, the movement is characterized by rapid directional fluctuations in the landscape space, gaining either positive or negative accumulation values. To depict these changes, we plot the accumulating response activation based on the current state of the system across iterated time (see Equation (2)), with iteration cycles along the y-axis (Fig. 8a). Oftentimes, as in the case of simulated other-centric responses, the accumulating values will progress towards an egocentric competitor (i.e., positive, leftward direction) before shifting towards the eventual target (i.e., negative, rightward direction), and will do so several times before reaching a response threshold. These trajectories approximate the same curvature behavior that

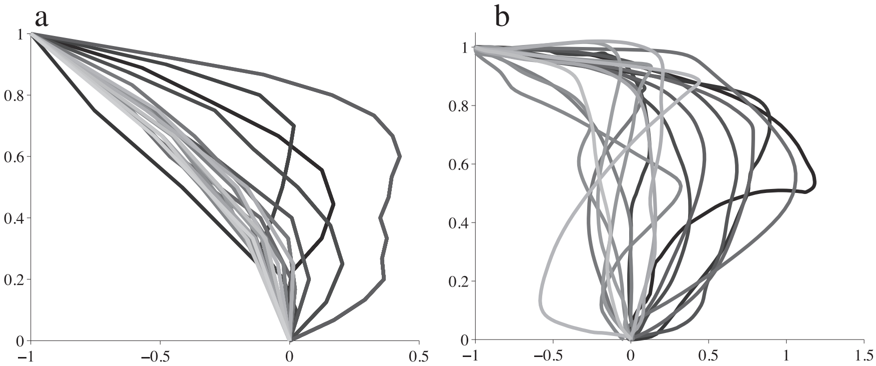

Fig. 8. (a) Other-centric trajectories produced by model for all trials, with darker to lighter colors correspond to increasing trial number, and (b) other-centric trajectories averaged over other-centric participants from experimental study. For both plots, curvature is toward egocentric response option (positive direction), where early "darker" trials show more response competition (i.e., curvature) than later "lighter" trials.

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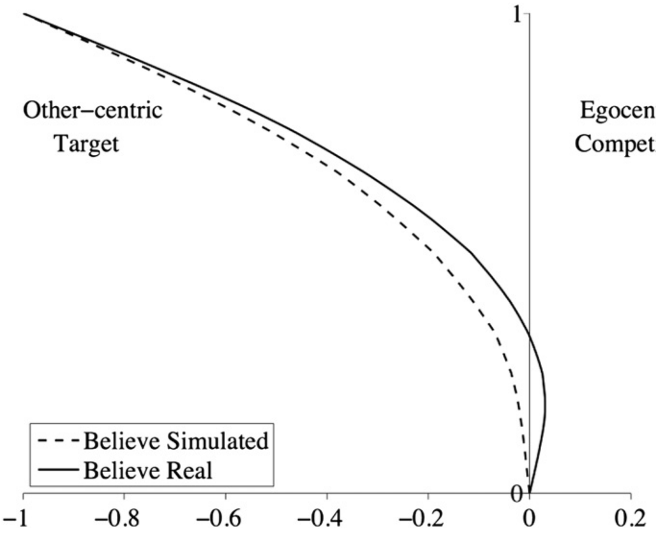

Fig. 9. Model trajectories for other-centric responses. There is less competition toward the egocentric response in the Believe Simulated condition compared to the Believe Real condition.

is evident in human mouse movement trajectories, albeit with less variation (see Fig. 8b).

Following a similar procedure as used with the analysis on human trajectories, we averaged the normalized other-centric trajectories produced by the model, with the resulting composite trajectories for each condition plotted in Fig. 9. Here, differences between conditions are clearly captured. Believe Simulated models show facilitated responding due to less competition with an egocentric competitor, elicited by the greater saliency of other-oriented attributional information represented by the model's control parameter and initial condition settings.

6.4. Summary

We have conceptualized perspective-taking as a low-dimensional order parameter of a system. This order emerges from dynamic behavior that takes place under particular control parameters. In the perceptuomotor domain, physical constraints such as visual coupling (Richardson et al., 2007), or movement frequency (Kelso, 1981), change relative patterns of movement between two limbs or two people, leading to a stable mode of rhythmic movement. In our case, we have considered control parameters as attributional states which warp a landscape of potential perspectives. In many social tasks, one must decide whether to take an ego- or other-centric perspective when interacting. As described further below, such simple social constraints can be seen as essential pieces of information that bias a system's "perspectival" landscape and thus its eventual behavioral strategy. Here we have shown that such an assumption, expressed in a very simple dynamical systems model, can simultaneously capture the endpoint response distribution, response time patterns, and response dynamics of human participants, at least on the qualitative surface. Importantly, this model is drawn from the very same kind of interpersonal dynamics observed in the perceptuomotor case.

7. Discussion

A dynamical systems approach to communication usually involves contexts where cognitive agents are *physically situated*, and their behavior coupled by perceptuomotor constraints. Extending it beyond such contexts has been a focus of recent discussion (e.g., Chemero, 2009; Schmidt, 2007). In other research domains, namely process models of discourse, cognition is described as occurring in contexts where agents are *informationally situated*; that is, where beliefs and implicit communicative goals drive comprehension. In this paper, we have attempted to bridge this explanatory gap by examining how language users make sense of ambiguous statements by means of coordinating perspective. We argue that attributes about one's communicative partner, which is information available in a social environment, influences how statements are disambiguated, and thereby how mutual understanding may unfold. This process adheres to general principles of dynamical systems, resulting in response behavior that is self-organized and sensitive to context and constraining variables.

To make our case, we used a modified version of the HKB model to simulate response data taken from Duran et al. (2011). The core model was originally developed to explain how coordinated finger oscillations are organized in time and space, and later adapted by Tuller et al. (1994) to characterize change in perceptual processes. Important for current purposes, the model's conceptual premise rests on a basic notion that the complex interactions behind a coupled, dynamical system can be captured by a single order parameter, constrained and ultimately guided by, one or more control parameters.

Extending this to the current work, we sought to characterize coupled behavior on a single dimension of perspective choice. Our justification for doing so is based on what happens in real dialog. In naturalistic conversations, language users may operate on an implicit agreement to

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minimize their own and each others' cognitive effort in reaching a shared understanding (e.g., principle of least collaborative effort). This type of reciprocal compensation requires coordination of thought and action, i.e., coupled behavior. Here, it is manifested in whether a participant chooses to interpret a partner's instructions from an ego- or other-centric perspective, and thus forms the basis of the model's order parameter. To characterize the control parameter, we must turn to the question of what guides a particular perspective choice. Again, based on the self-other contingencies that arise through social interactions, participants are highly attuned to the characteristics of others that might make it more or less difficult for them to contribute to the goal of shared understanding. It is these attributional constraints that guides an individual's perspective choice, with greater perceived difficulty increasing the likelihood of other-centric responding. As such, in the current simulation, the control parameter is the attributional information that trigger particular response choices.

The results of the model simulation generated an array of response patterns that were consistent with human behavior. In both the simulation and data, we found differences in end point response distributions that indicate multi-stable interpretations (e.g., both other-centric and egocentric responders under the same task conditions), as well as the simultaneous activation of multiple response biases whose attractor strength was modulated within and across trials. Taken together, the emergent dynamical signatures suggest that the comprehension system self-organizes by rapidly integrating attributional constraints. This provides further evidence for a collaborative process model of discourse, where the act of understanding is shaped by a social partner within a shared goal space (Brown-Schmidt & Hanna, 2011).

As is typical in the majority of studies that examine global sources of attributions during language comprehension, we assume that the most salient sources are those that can be heuristically induced to two alternatives. Here, we chose to look at whether participants believed their partner to be real or not (as has been done elsewhere, see Brennan, 1991; Schober, 1993). There are a number of other examples that could be evaluated, as in whether participants believed that they are looking at the same thing as their partner (Brennan, 2004), whether an object is accessible to both them and their partner (Hanna & Tanenhaus, 2004), and so forth. As Brennan et al. (2010) note, such either/or attributions allow for an immediate influence on language comprehension and production. Thus, participants do not need to construct complex inferences about their partner to communicate effectively. The current model provides additional support to this theoretical claim by explicitly employing binary attributions. Nevertheless, this does not preclude other forms of input, such as local sources of attributional information that accumulate during the course of a single interaction. For example, participants might become more other-centric as they notice their partners using an increasing number of speech disfluencies. To model such a scenario, continuous input to the control parameter would be appropriate, thereby allowing possible transitions between perspective-taking behavior to occur. Insights about attributional influence could then be made by examining additional HKB dynamical properties, such as hysteresis and critical instabilities around transition points (for possible extensions, see Tuller et al., 1994 or Raczaszek, Tuller, Shapiro, Case, & Kelso, 1999 as examples).

Another promising direction that is related to the above is in capturing the multiple shifts between perspective types that occur in descriptions of visual scenes, such as participants who spontaneously switch between route and survey perspectives (Taylor & Tversky, 1996), or in locating a referent for another during online comprehension and production tasks (Schober, 1995; Tversky, Lee, & Mainwaring, 1999). Thus, in dialog situations where referent saliency or the cognitive ease in using certain referential expression is varied, the model would capture, and therefore predict, the back and forth movement across any number of perspective attractor states. By doing so, the relevance of the various factors thought to influence perspective-taking could be better understood, specifically in terms of how quickly they stabilize the overall system, and whether this stabilization turns out to be weak and transitory, or robust and long-lasting.

However, as our findings currently stand, they already have the potential to augment accounts of communicative coordination, such as those based on a mechanism of priming. As described earlier, these accounts assume early separation between egocentric processes and social factors, whereby interaction between the two only occurs after the more fast-acting egocentric processes are reflexively executed. Instead, coordination behavior, at least as it is manifested here in response choice, is better characterized as immediate, simultaneous activation of both ego- and other-centric constraints. This implies a processing system that is not limited by assumptions of ego- or other-centric defaults, but instead is able to exhibit "multipotentiality," whereby the system integrates both perspective types from the start. This is comparable to dynamical accounts of lexical access and sentence processing reported elsewhere (Kawamoto, 1993; Raczaszek-Leonardi, Shapiro, Tuller, & Kelso, 2008). Furthermore, such integration allows response resolution to be expressed as nonlinear competition over time, acting to reorganize the system as a whole into more and more stable modes. In this way, orientation toward a particular perspective type becomes more efficient as a function of response histories that unfold across various time scales. By characterizing the perspective-taking system as a dynamical interaction, it imbues the system with greater sensitivity to social influences than what other accounts might allow.

Lastly, we also show that bistable coordinative dynamics of HKB and related dynamical systems models can go beyond basic perceptuomotor tasks. Our aim was to show that even informational contexts in the social domain, here social attributions in a simulated interactive task, shape perspective-taking strategy. We have conceptualized this strategy in an admittedly simple way, but this is consistent with previous work, in which multiple-constraint satisfaction systems are explored in terms of their lower-dimensional behavioral orders (see for example Onnis & Spivey, 2012; for a discussion of such a strategy; see also van Rooij et al., 2002). Our results overall suggest a

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commonality of dynamic structure at various levels in human communication, whether perceptuomotor in dynamic face-to-face conversation, or more informational as in when we are not looking at each other at all but having to coordinate on some task. Even in this latter case, we face such situations frequently on a day-to-day basis. We share a computer screen or a work of art while we chat (Richardson & Dale, 2005), or we discuss recent events over the phone, or we coordinate our plans over text or instant messenger. Human beings are capable of doing this decoupling from their perceptuomotor contexts. What we are suggesting in this paper, and hope to have at least lent some promise to, is the notion that these decoupled cognitive dynamics may admit of similar dynamical structure that is worthy of exploration.

Acknowledgments

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