Proceedings of the Annual Meeting of the Cognitive Science Society

How spatial simulations distinguish "tracking" verbs

Proceedings of the Annual Meeting of the Cognitive Science Society, 46(0)

Kon, Maria
Khemlani, Sangeet

2024

How spatial simulations distinguish “tracking” verbs

Maria Kon[1*] and Sangeet Khemlani[1]
maria.kon.ctr@nrl.navy.mil and sangeet.khemlani@nrl.navy.mil
Navy Center for Applied Research in Artificial Intelligence
U.S. Naval Research Laboratory, Washington, DC 20375 USA
[*]National Academies of Sciences, Engineering, and Medicine Postdoctoral Research Associate

Abstract

We describe the verbs *pursue*, *chase*, and *follow* as “tracking” verbs because they share conceptual similarities: they are all motion verbs that describe a dynamic spatial relation between two entities, as in “the cat chased the mouse”. What distinguishes them from one another? If, as some cognitive scientists argue, mental simulations underlie the way the mind processes all motion verbs — including those that describe static scenarios, such as *run* in “the road runs through the desert” — then those simulations may explain the differences between tracking verbs. For instance, *chase* and *pursue* may describe conceptually faster motion than *follow*. We tested this hypothesis in two experiments. The studies presented participants with imagery of one car chasing another along a straight road. In Experiment 1, participants estimated the distance that the pursued car would travel 3 seconds into the future by dragging a slider to an appropriate point on the road. In Experiment 2, participants estimated the distance by selecting from several distance options on a logarithmic scale. Both studies validated the hypothesis that *chase* and *pursue* describe faster motion, i.e., participants reliably estimated longer distances for descriptions that included those verbs. We place the results in the context of broader theories of pursuit perception and verb comprehension.

Keywords: tracking verbs, mental simulation, motion verbs, fictive motion, spatial reasoning

Introduction

Consider these three sentences:

1a. The cat chased the mouse.
b. The cat pursued the mouse.
c. The cat followed the mouse.

The verbs *chase*, *pursue*, and *follow* are all “tracking verbs”: they describe dynamic spatial relations between two separate agents, where one agent moves towards another. They are similar to other motion verbs such as *jump* and *fall*, because they all describe motion relations that people can perceive (Frankenhuis, Bouse, Barrett, & Johnson, 2013; Gao, Newman, & Scholl, 2009; Gao & Scholl, 2011; Ji, Ward, & Green, 2023; Meyerhoff, Schwan, & Huff, 2014). But, whereas *jump* and *fall* describe static interactions (i.e., punctate events that don’t necessarily refer to a time interval), *chase, pursue,* and *follow* are all dynamic: they concern interactions that endure over multiple points in time. The verbs *jump* and *fall* concern changes in a particular direction: *jump* concerns upward motion and *fall* concerns downward motion. In examples (1a-c) the pursuer (cat) and the target (mouse) can exhibit state changes in any direction, so long as at least two conditions hold. The first is that the positions of the pursuer and target make similar trajectories across space, and therefore define a path (see Talmy, 1985, p. 85). Hence, the cat is not pursuing, chasing, or following the mouse if both animals are changing positions by jumping up and down in place. Likewise, no pursuit holds if the cat is moving in the opposite direction as the mouse. The second condition is that the target’s spatial translation across the path occurs *before* the pursuer’s (see, e.g., Miller & Johnson-Laird, 1976, p. 538). If the cat traverses a path before the mouse does, then the mouse is following the cat but not vice versa. These two conditions appear to hold for all tracking verbs. Hence tracking verbs have considerable semantic overlap with one another. What distinguishes them from one another?

One clue may come from investigations into sentences such as (2a) below:

2a. Road 49 crosses the desert.
b. Road 49 is in the desert.

This example uses a motion verb (*cross*), but it describes a static scenario in which both subject and object exhibit no state changes. According to some theorists, the sentence in (2a) concerns fictive motion, i.e., an implicit form of motion that corresponds to the ways in which stationary objects relate to one another (Langacker, 1986; Matsumoto, 1996; Talmy, 1983, 1996). In contrast, (2b) describes a similar situation without a motion verb, and therefore does not yield fictive motion. Matlock (2004) hypothesized that people represent fictive motion sentences by mentally simulating objects in physical space (see, e.g., Knauff, 2013), and that motion verbs help people construct and trace static spatial models in the same way they might mentally simulate motion along the paths represented by those models (e.g., Battaglia, Hamrick, & Tenenbaum, 2013; Gerstenberg, Peterson, Goodman, Lagnado, & Tenenbaum, 2017; Khemlani, Mackiewicz, Bucciarelli, & Johnson-Laird, 2013). She shows in a series of studies that people are faster to react to sentences akin to (2a) than (2b), and likewise, that they’re faster to interpret fictive motion along short distances and easy terrains (Matlock, 2004, 2010; see also Denis & Cocude, 1989; Kosslyn et al., 1978; Ramscar, Matlock, & Boroditsky, 2009). Sentences that include motion verbs appear to trigger the construction and online processing of spatial simulations, so long as those sentences describe literal situations about spatially grounded objects (Bergen, Lindsay, Matlock, & Narayanan, 2007; von Subbe et al., 2021).

The different tracking verbs in (1) may therefore yield different spatial simulations. Those simulations may be structurally similar, i.e., they may represent two objects that follow the same trajectories (see Figure 1). The manner in

In L. K. Samuelson, S. L. Frank, M. Toneva, A. Mackey, & E. Hazeltine (Eds.), *Proceedings of the 46th Annual Conference of the Cognitive Science Society.*

which the mind scans and builds each simulation may differ systematically, however, and such differences may serve to distinguish the three verbs. In the next section, we summarize why motion verbs yield mental simulations. We highlight potential differences in the way the mind simulates *chase, pursue*, and *follow*, and we outline predictions for how individuals might reason prospectively based on those simulations. We next describe two experiments that tested and validated those predictions. We conclude with a discussion of additional ways to distinguish verbs of motion.

Motion verbs and mental simulations

The lexical semantics of many motion verbs can encode complex background knowledge (Cadiot, Lebas, & Visetti, 2006; Miller & Johnson-Laird, 1976; Papafragou & Selimis, 2010; Tenny, 1995; Wälchli, & Cysouw, 2012). Consider the verbs *walk* and *run*: walking is a behavior that is typically slower than running, and perhaps that difference is part of the meaning of the verb. From it, the following abstract inference seems compelling:

3. An individual who walks for 10 minutes will have traveled a shorter distance than if they had run during that same period.

To arrive at (3), you needn't construct any mental simulation whatsoever: you may instead remember that *distance* = *speed* * *time*, that the rate of walking is typically slower than the rate of running, and that the time is a constant (10 minutes), and so the distance traveled is bound to be smaller for *walk* than for *run*. The pattern of reasoning appeals to explicit physical and algebraic knowledge, but it depends on several assumptions, such as that walking and running should occur in equivalent contexts. What happens when those assumptions break down? Consider an individual who travels twice as far on a 10-minute walk than a 10-minute run. Before reading further, consider how you might explain the situation. Here are a few reasons:

4a. The man ran on a treadmill but walked on straight path;
b. The man walked healthy but ran sick or injured;
c. The man ran up a hill but walked down it;
d. The man ran through mud but walked on asphalt;

These examples illustrate that physical laws depend on the explicit specification of many parameters, and that (3) serves as a general rule only if all else is equal. Indeed, it is implausible that a lexical semantics encodes all such considerations, and equally implausible that people carry out the complex physical and algebraic calculations necessary to capture the intutions in (4a-d) (but cf. Battaglia et al., 2013 and Gerstenberg et al., 2017).

How might people represent and reason about the consequences of sentences that include motion verbs such as *run* and *walk*? One account of spatial language interpretation and reasoning argues that the mind doesn't directly reason based on the knowledge encoded in lexical semantics or formal rules of inference; rather, it uses lexical knowledge to build iconic simulations of relevant scenarios (Byrne & Johnson-Laird, 1989; Hegarty, 2004; Tversky, 1991; 1993). Intuitive reasoning depends on constructing an initial "mental model", then scanning it to make rapid inferences (Johnson-Laird, 1983, 1996); deliberation proceeds by considering alternative models of the premises by fleshing initial models out or by integrating relevant background knowledge (Khemlani et al., 2018). Such models can represent dynamic relations through the piecemeal analysis of a kinematic sequence (Hegarty, 2004; Khemlani et al., 2013). Figure 1 depicts spatial models of sentences with motion verbs. Panels (i) and (ii) in the figure show how a single token representing a cat can be updated in discrete steps along a single dimension representing a path. Indeed, evidence shows that toddlers can mentally represent paths and manners of motion when interpreting motion verbs (see Golinkoff & Hirsh-Pasek, 2008). Panels (iii) and (iv) extend this treatment to capture how people might represent the distinctions between tracking verbs (1a-c), namely that different verbs may yield different

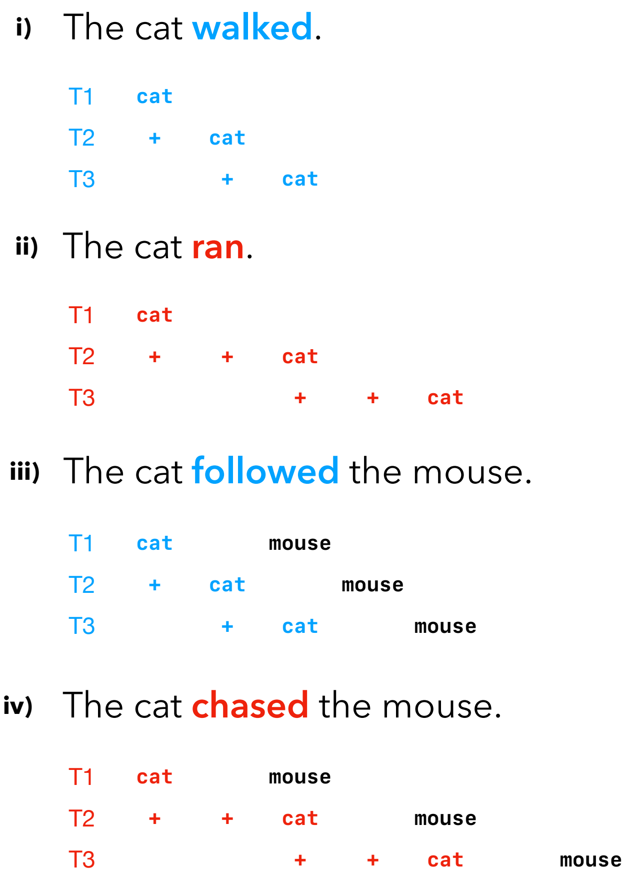


Figure 1. Schematic diagrams of kinematic spatial models that simulate four separate sentences with motion verbs. Each diagram includes tokens that stand in place of simulations of agents (e.g., 'cat') as well as time points (T1-T3) that depict each step in a kinematic sequence. The +s in each diagram denote discrete portions of a path that a token is translated across. The motion verbs *walk* (i) and *run* (ii) may differ in how spatial models are updated over time such that running yields larger traversals than walking. A similar difference explains the distinction between *follow* (iii) and *chase* (iv).

forms of translation over an axis representing a path. We therefore posit the following *tracking verb hypothesis*:

> The verbs *chase*, *pursue*, and *follow* yield distinct patterns of mental simulations: *chase* and *pursue* trigger simulations of more rapid movement, i.e., greater amounts of translation along a given path than *follow*.

One way to test the hypothesis is to ask people to estimate the distance traveled by a pursuer and a target while varying the verb used to describe their relation. We describe two experiments that adopted this methodology.

Experiment 1

Experiment 1 tested whether people's prospective inferences about the movements of objects depends on their interpretation of *chase*, *pursue*, and *follow*. Participants in the study saw static diagrams depicting two cars on a straight road. For each problem, they read descriptions such as: *the blue car is chasing the yellow car*. Their task was to estimate where the yellow car would be after 3 seconds by dragging a slider along a path defined by the road (see Figure 2).

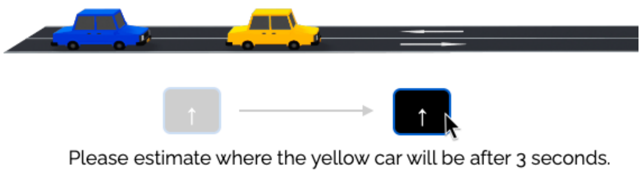
The experiment manipulated the tracking verb in the descriptions. If people mentally distinguish the motion verbs *chase* and *pursue* by shifting mental tokens along a spatial representation analogous to a path, and if they do so more rapidly for those two verbs than for *follow*, and if they base prospective inferences on the outcomes of such simulations, they should drag the slider farther to the right. Otherwise, if these conditions do not hold, and indeed, if semantic distinctions between the three tracking verbs are unrelated to fictive motion, then there should be no differences in how far participants drag the slider.

Method

Participants. We conducted a power analysis using the `pwr` package (Champely et al., 2018) in R. The goal of Experiment 1 was to obtain .85 power to detect a medium effect (d = 0.5; similar to the sorts of effects observed in previous investigations on fictive motion) at .01 α error probability, and so 46 participants were required for the study. 60 participants (mean age = 42.9 years; 29 females, 30 males, and 1 non-binary) volunteered through Amazon Mechanical Turk. 1 participant reported not being a native English speaker, and so their data were discarded. The reported analyses concern the remaining participants' data.

Open science. The code used to conduct Experiment 1, as well as experimental stimuli, data, and analysis scripts are available on OSF (**https://osf.io/9ks8a**).

Design, procedure, and materials. The experiment presented participants with 12 problems concerning the movements (or lack thereof) of two colored cars on a straight road (see Figure 2). On each problem, participants evaluated the cars relative to a sentence description of the scene. Half of the problems (i.e., experimental problems) described the scene using a tracking verb (e.g., *the green car is following the white car*). Half were controls (e.g., *the green car is parked and the white car is moving forward slowly)*. The experiment randomly assigned 12 separate color pairs (e.g., *blue-yellow, green-white,* and so on) to the 12 problems. Specific color values were drawn from a colorblind-friendly palette (Wong, 2011). On each problem, a slider handle (marked by '↑') was placed in between the two cars, and participants had to adjust the slider to a location along the road to estimate where a specific car will be after 3 seconds. Half of the prompts in the study referred to the car in front (e.g., the yellow car in Figure 2) and half referred to the car behind. Descriptions in control problems were sentences that used the neutral motion verb "moving":



Please estimate where the yellow car will be after 3 seconds.

Figure 2. The slider task used in Experiment 1 to assess prospective inferences about where a car will end up after a given period of time. On each problem, a slider handle appeared between the two cars, and participants had to drag it to a location that satisfied their intuitions about how far the specified car would move.

The green car is parked and the white car **is parked too**.
The green car is parked and the white car **is moving forward slowly**.
The green car is parked and the white car **is moving forward quickly**.

If tracking verbs yield more fictive motion than neutral motion verbs, then participants should move the slider farther to the right for experimental problems than for control problems. If control problems yield any fictive motion whatsoever, participants should exhibit a trend in their slider adjustments: less of a positional shift for "parked too", more of a shift for "slowly", and even more of a shift for "quickly". Participants could shift the slider along the full range of the road depicted in Figure 2 such that the left edge of the road denoted 0 and the right edge of the road denoted 100. Participants could not complete the next trial without making some shift to the slider's position. The order of the stimuli was randomized for each participant. The experiment therefore yielded 6 separate conditions (3 experimental: *chase*, *pursue*, *follow*; 3 control: *parked, slowly*, *quickly*) x 2 types of prompt referents (car in front vs. car behind) fully repeated measures design.

Results and discussion

Participants estimated larger distances of travel for experimental than control problems (mean slider value = 72.4 for experimental vs. 52.1 for control; Wilcoxon test, $z = 6.08$, $p < .001$, Cliff's $\delta = .60$). Their responses to control problems yielded a significant trend: lower estimates for *parked* controls (mean slider value = 42.2), middling estimates for *slowly* (mean slider value = 50.5), and higher estimates for *quickly* (mean slider value = 63.7; Page's trend test, $z = 7.23$, $p < .001$), which serves as a conceptual replication of

Matlock's (2004) experiments on fictive motion. The results likewise demonstrate systematic comprehension of the task.

The results from Experiment 1 corroborated the tracking verb hypothesis: participants made larger estimates for *pursue* (mean slider value = 74.1) and *chase* (mean slider value = 74.9) than for *follow* (mean slider value = 68.1). Pairwise analyses showed reliabled differences between *pursue* and *follow* (Wilcoxon test, $z = 4.35$, $p < .001$; Cliff's $\delta = .20$) and between *chase* and *follow* (Wilcoxon test, $z = 4.37$, $p < .001$, Cliff's $\delta = .23$). There were no reliable differences in estimates between *pursue* and *chase* (Wilcoxon test, $z = -1.35$, $p = .18$, Cliff's $\delta = -.04$). 32 out of 59 participants yielded their lowest mean slider values for *follow* compared to the other verbs (binomial test, p = .001 with a prior probability of 1/3).

Experiment 1 showed that participants make larger estimates of movement for *pursuit* and *chase* than for *follow*. These results corroborate the tracking verb hypothesis. Nevertheless, while the differences between *pursuit* and *follow* were reliable, they did not yield large differences in distance estimates, and so it in unclear whether individuals systematically distinguish them on the basis of their tendency to induce more or less fictive motion. The experiment was limited in several ways: for instance, it included no attentional check to ensure that participants understood the task at hand. It was clear from their aggregated responses to control problems that they answered sensibly and systematically, but there existed no reason to reject individual participants on the basis of their performance alone. Likewise, the task asked participants to make estimates by dragging a slider across the screen, and those mouse movements themselves, and not any mental simulation per se, may have inappropriately cued participants to think in terms of linear transformations that yield spurious differences between verbs. Experiment 2 addressed both of these limitations and found consistent results.

Experiment 2

Experiment 2 adopted a design that was similar in every respect to Experiment 1, except that it presented participants with a forced-choice task to elicit their distance estimations. Instead of the slider depicted in Figure 1, participants selected one of six distinct options to respond to the question, "Please estimate how far the [colored] car will travel after 3 seconds":

0 feet	1 foot	10 feet	100 feet	1000 feet	10,000 feet
☐	☐	☐	☐	☐	☐

The options reflect a logarithmic response scale, and they were presented to participants vertically. If the difference between *chase* and *follow* observed in Experiment 1 is systematic, then the same pattern should emerge on a logarithmic scale as well. Experiment 2 used a forced-choice task to prevent participants from mapping the linear motion of a mouse-drag to a numerical estimate of distance.

The scale also permitted a novel form of quality control: participants who received a trial describing two stationary vehicles should sensibly respond that neither car will make any movements after 3 seconds – they should select "0 feet" as their response option. Those who chose any other response may have failed pay attention on that problem. Experiment 2 permitted us to discard their data.

Method

Participants. 56 participants (mean age = 43.73 years; 21 females, 34 males, and 1 non-binary) volunteered through Amazon Mechanical Turk. 1 participant reported not being a native English speaker, and so their data were discarded. Likewise, 6 participants produced average distance estimates > 0 for control problems in which cars were stationary, and so their data were discarded also. The reported analyses concern the remaining 49 participants' data.

Open science. The code used to conduct Experiment 2, as well as experimental stimuli, data, and analysis scripts are available on OSF (**https://osf.io/9ks8a**).

Design, procedure, and materials. The design, procedure, and materials were the same as in Experiment 1: participants received 12 problems depicting two colored cars along a road, as well as a premise describing their relation. It implemented a 6 (problem type) x 2 (prompt referent, i.e., car in front vs. car behind) fully repeated measures design. The experiment presented participants with 12 problems concerning the movements (or lack thereof) of two colored cars on a straight road (see Figure 2). On each problem, participants estimated how far a specific car would travel after 3 seconds by choosing one of several options: 0 feet, 1 foot, 10 feet, 100 feet, 1000 feet, or 10,000 feet. They could move onto the next problem only after selecting an option.

Results and discussion

Figure 3 shows the distance estimates that participants made in Experiment 2. The patterns replicated those of the previous study: participants estimated larger distances of travel for experimental than control problems ($M = 442.9$ for experimental vs. $M = 61.6$ for control; Wilcoxon test, $z = 5.47$, $p < .001$, Cliff's $\delta = .57$). Their responses to control problems yielded a significant trend: zero distance for *parked* controls ($M = 0.0$), small distances for *slowly* ($M = 13.0$), and larger distances for *quickly* ($M = 171.8$; Page's trend test, $z = 9.80$, $p < .001$), which once more demonstrates systematic comprehension of the task. (These trends also hold when all 56 participants' data are included.)

In Experiment 2, as in Experiment 1, participants made larger estimates for *pursue* ($M = 566.0$) and *chase* ($M = 644.0$) than for *follow* (mean slider value = 119.0). Pairwise analyses revealed significant differences between *pursue* and *follow* (Wilcoxon test, $z = 3.85$, $p < .001$; Cliff's $\delta = .31$) and between *chase* and *follow* (Wilcoxon test, $z = 5.15$, $p < .001$, Cliff's $\delta = .41$). There was a marginal difference between *pursue* and *chase* (Wilcoxon test, $z = 1.83$, $p = .07$, Cliff's $\delta = .12$).

In sum, Experiment 2 corroborated the tracking verb hypothesis using a separate measure.

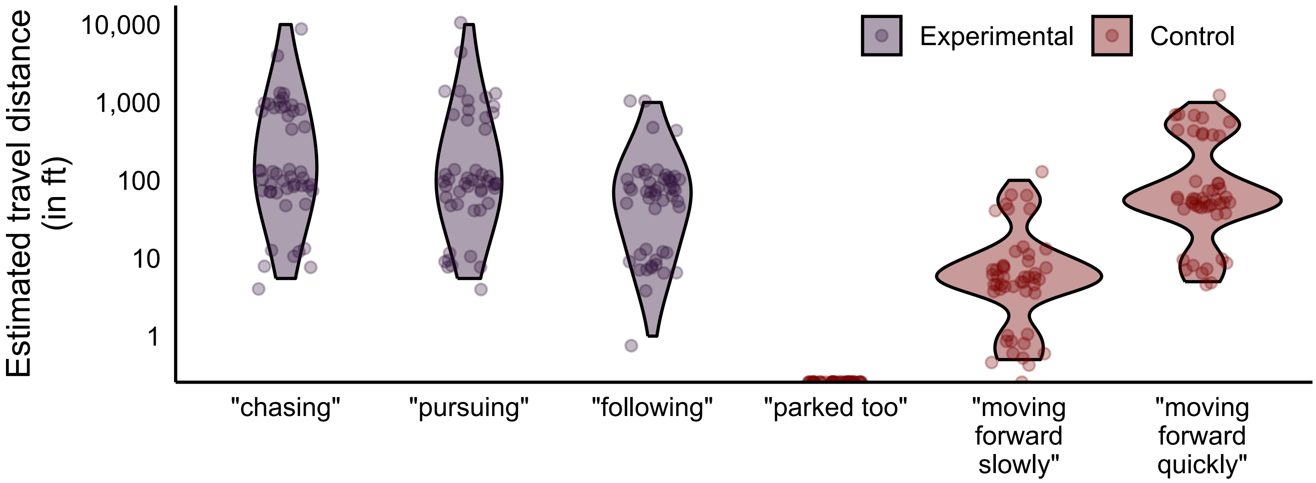


Figure 3. Violin plots of mean estimates of travel distance in Experiment 2 as a function of the verb used to describe the static image presented to participants.

General discussion

Two experiments revealed systematic differences in the way people interpret *chase* and *follow*: they received static images of a pursuer and its target, and they inferred larger distances of travel for *chase* than for *follow*. The same was true for *pursue* versus *follow*. The three tracking verbs share a similar semantics: they all describe some form of motion, and they refer to dynamic, directional spatial relations between two entities (a pursuer and a target). One reason that *chase* and *pursue* yield relatively larger distance estimates may be because of how the mind represents and dynamically updates those spatial relations. We hypothesize that to represent dynamic relations, people first construct and maintain spatial models of the pursuer and the target, and then translate them kinematically along a given path, i.e., by making small, iconic changes to them. Differences between motion verbs may amount, in part, to how those verbs direct the construction and manipulation of mental simulations, such that *chase* yields greater translation across a path than *follow.* The evidence bears out this hypothesis.

The evidence we outlined above is tentative, because the experiments we ran have several limitations. For example, both studies reveal differences in processing *chase* and *follow* in the context of cars moving along a road. We expect that the differences should generalize to other physical contexts as well, such as (1), and future research should implement such extensions. Another limitation of the studies is that participants made distance estimates for all three tracking verbs across all the problems they received: the experiments manipulated the verb as a within-participants factor. This choice of design may have caused participants to make explicit comparisons between the different tracking verbs (and the control verbs) when they otherwise would not. Replicating the results above in a between-participants version of the experiments would help dispel such concerns.

We conclude by anticipating other pragmatic and semantic considerations that may distinguish *pursue*, *chase*, and *follow.* The studies we outline show similarity between people's distance estimates for *pursue* and *chase*, and indeed, many scientific investigations into the perception of chasing movements use the concepts of "pursuit" and "chasing" interchangeably, e.g., Gao et al., 2009, p. 177 (italicized for emphasis):

> "…certain types of directionality are so powerful that they can induce the perception of *chasing* even where is no actual *pursuit*…"

But perhaps one factor that distinguishes *pursue* from *chase* are the contexts and manner of their usage (see, e.g., Bybee, 2010; Goldberg, 2019). A corpus-based study by Barr (2015) examing chase and pursue supports this claim, concluding that, e.g., *pursue* tends to be used in a figurative sense and in more formal contexts, while *chase* tends to be used literally and in casual contexts. Consider these statements:

5a. Asha chased the dog all over the yard.
b. Asha pursued a degree in physics.
c. ? Asha pursued the dog all over the yard.
d. ? Asha chased a degree in physics.

The first two seem like reasonable statements to make, whereas the last two may not be (denoted by '?'). It may be that *chase* is more felicitous for physical targets (e.g., the dog) whereas *pursue* is more felicitous for more abstract targets (the degree). Indeed, (5c) seems infelicitous, because it seems that *pursue* is too formal a term in this context; whereas (5d) may be acceptable, though it seems to imply something different than (5b), namely that (5d) hints at the possibility that Asha is experiencing difficulty achieving her goal. Indeed, perhaps *chase* implies more effortful activity than *pursue*.

The different verbs may also yield differences in propositional attitude inferences. Propositional attitudes concern the mental states that individuals maintain towards propositions, e.g., believing, knowing, wanting, and predicting. Compare this inference:

6. Asha is chasing Tony.
   Therefore, Tony knows he is being chased.

in which the conclusion seems sensible, with this one:

7. Asha is following Tony.
   # Therefore, Tony knows he is being followed.

in which the conclusion is wrong (denoted by '#'): individuals can be followed without their knowledge, alas. Asymmetries such as these may further distinguish tracking verbs.

To summarize, you can both visualize and conceptualize a chase. Several cues help you to perceive chasing behavior, such as the manner in which a pursuer moves towards its target. Indeed, simulations of perceptual events may help individuals discuss and describe chases, which in turn they can simulate by constructing and animating spatial models. We describe preliminary evidence that individuals distinguish between chasing, following, and pursuit by the ways in which they mentally animate those models.

Acknowledgments

This work was supported by a National Research Council Associateship Award to MK, and data were collected by Knexus Research Corporation. This work was also supported by a grant from the Naval Research Laboratory awarded to SK. The views expressed in this paper are solely the authors' and should not be taken to reflect any official policy or position of the United States Government or the Department of Defense.

References

Battaglia, P. W., Hamrick, J. B., & Tenenbaum, J. B. (2013). Simulation as an engine of physical scene understanding. *Proceedings of the National Academy of Sciences*, 110(45), 18327-18332.

Bergen, B. K., Lindsay, S., Matlock, T., & Narayanan, S. (2007). Spatial and linguistic aspects of visual imagery in sentence comprehension. *Cognitive Science*, 31, 733-764.

Barr, B. W. (2015). Chase or pursue: a corpus-based study. In *JALT2014 Conference Proceedings* (pp. 364-377).

Bower, G. H., & Morrow, D. G. (1990). Mental models in narrative comprehension. *Science*, 247, 44-48.

Bybee, J. (2010). *Language, usage and cognition.* Cambridge University Press.

Byrne, R. M., & Johnson-Laird, P. N. (1989). Spatial reasoning. *Journal of Memory and Language*, 28, 564-575.

Cadiot, P., Lebas, F., & Visetti, Y. M. (2006). The semantics of the motion verbs. *Space in Languages: Linguistic Systems and Cognitive Categories*, 66, 175.

Denis, M., & Cocude, M. (1989). Scanning visual images generated from verbal descriptions. *European Journal of Cognitive Psychology*, 1, 293-307.

Frankenhuis, W. E., House, B., Barrett, H. C., & Johnson, S. P. (2013). Infants' perception of chasing. *Cognition*, *126*, 224-233.

Gao, T., Newman, G. E., & Scholl, B. J. (2009). The psychophysics of chasing: A case study in the perception of animacy. *Cognitive Psychology*, 59, 154-179.

Gao, T., & Scholl, B. J. (2011). Chasing vs. stalking: interrupting the perception of animacy. *Journal of Experimental psychology: Human Perception and Performance*, 37, 669.

Gerstenberg, T., Peterson, M. F., Goodman, N. D., Lagnado, D. A., & Tenenbaum, J. B. (2017). Eye-tracking causality. *Psychological science*, 28(12), 1731-1744.

Goldberg, A. E. (2019). *Explain me this: Creativity, competition, and the partial productivity of constructions*. Princeton University Press.

Golinkoff, R. M., & Hirsh-Pasek, K. (2008). How toddlers begin to learn verbs. *Trends in Cognitive Sciences*, 12, 397-403.

Hegarty, M. (2004). Mechanical reasoning by mental simulation. *Trends in Cognitive Sciences*, 8, 280-285.

Johnson-Laird, P. N. (1983). *Mental models: Towards a cognitive science of language, inference, and consciousness*. Harvard University Press.

Johnson-Laird, P. N. (1996). Space to think. In P. Bloom, M. A. Peterson, L. Nadel, & M. F. Garrett (Eds.), *Language and space* (pp. 437–462). MIT Press.

Ji, M., Ward, E. J., & Green, C. S. (2023). Realistic and complex visual chasing behaviors trigger the perception of intentionality. *PLOS One*, 18, e0284485.

Khemlani, S., Mackiewicz, R., Bucciarelli, M., & Johnson-Laird, P.N. (2013). Kinematic mental simulations in abduction and deduction. *Proceedings of the National Academy of Sciences*, 110, 16766–16771.

Knauff, M. (2013). *Space to reason—A spatial theory of human thought.* Cambridge, MA: MIT Press.

Langacker, R. W. (1986). Abstract motion. In V. Nikiforidou, M. VanClay, M. Niepokuj, & D. Feder (Eds.), *Proceedings of the Twelfth Annual Meeting of the Berkeley Linguistics Society* (pp. 455-471). Berkeley: University of California, Berkeley Linguistics Society

Matlock, T. (2010). Abstract motion is no longer abstract. *Language and Cognition*, 2, 243-260.

Matlock, T. (2004). Fictive motion as cognitive simulation. *Memory & Cognition*, 32, 1389-1400.

Matsumoto, Y. (1996). Subjective motion and English and Japanese verbs. *Cognitive Linguistics*, 7, 183-226.

Meyerhoff, H. S., Schwan, S., & Huff, M. (2014). Perceptual animacy: visual search for chasing objects among distractors. *Journal of Experimental Psychology: Human Perception and Performance*, 40, 702.

Miller, G. A., & Johnson-Laird, P. N. (1976). *Language and perception.* Harvard University Press.

Papafragou, A., & Selimis, S. (2010). Lexical and structural biases in the acquisition of motion verbs. *Language Learning and Development*, 6, 87-115.

Ramscar, M., Boroditsky, L., & Matlock, T. (2009). Time, motion and meaning: The experiential basis of abstract thought. In K. S. Mix, L. B. Smith, & M. Gasser (Eds.), *The Spatial Foundations of Language and Cognition* (pp. 67–86). Oxford, England: Oxford University Press.

Talmy, L. (1996). Fictive motion in language and "ception." In P. Bloom, M. A. Peterson, L. Nadel, & M. F. Garrett (Eds.), *Language and space* (pp. 211-276). Cambridge, MA: MIT Press.

Talmy, L., (1985). Lexicalization patterns: Semantic structure in lexical forms. In T. Shopen (Ed.), *Language typology and semantic description vol. 3: Grammatical categories and the* *lexicon* (pp. 36-149). Cambridge, Cambridge University Press.

Tenny, C. L. (1995). How motion verbs are special: The interaction of semantic and pragmatic information in aspectual verb meanings. *Pragmatics & Cognition*, 3, 31-73.

Tversky, B. (1991). Spatial mental models. *Psychology of Learning and Motivation*, 27, 109-145.

Tversky, B. (1993). Cognitive maps, cognitive collages, and spatial mental models. In *European Conference on Spatial Information Theory* (pp. 14-24). Berlin, Heidelberg: Springer Berlin Heidelberg.

von Sobbe, L., Ulrich, R., Gangloff, L., Scheifele, E., & Maienborn, C. (2021). Is rushing always faster than strolling? A reaction time study on the processing of sentences containing manner of motion verbs. *Acta Psychologica*, 221, 103428.

Wälchli, B., & Cysouw, M. (2012). Lexical typology through similarity semantics: Toward a semantic map of motion verbs. *Linguistics*, *50*, 671-710.

Wong, B. (2011). Color blindness. *Nature Methods*, 8, 441.