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Do we think about time in terms of space?

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Abstract

The human capacity for abstract thought poses an unsolved problem for the neural and cognitive sciences. How are people able to think about things that they can never see or touch, like ideas, mathematics, or time? A potential solution has emerged independently from such diverse fields as evolutionary biology and cognitive linguistics: the mind recruits old structures for new uses. It has been proposed, for example, that sensory and motor processes underlying spatial cognition are co-opted to support our thinking about phenomena such as mathematics and time. Empirical support for this proposal has been elusive. Until recently, arguments have rested largely on patterns observed in human language. Here we present a series of psychophysical experiments that investigate mental representations in the abstract domain of time and in the perceptually richer domain of space. Results show that people rely on spatial information to estimate time, but not the other way around. These studies provide some of the first entirely nonlinguistic evidence that spatial representations subserve temporal representations, and suggest a new way to explore the perceptual foundations of abstract thought.

Introduction

As humans, we have the unique capacity to think about immaterial things that we can never experience through the senses (e.g., courage, gravity, electrons), as well as imaginary things that we can never experience at all (e.g., negative numbers, time travel). How do we do it? One hypothesis is that we mentally represent abstract entities that we cannot see or touch in terms of things that we can perceive directly (Boroditsky, 2000; Boroditsky & Ramscar, 2002; Emmory, 2001; Gattis, 2001; Gibbs, 1994; Goldstone & Barsalou, 1998; Lakoff & Johnson, 1980, 1999; Pinker, 1989, 1997; Talmy, 1988). In support of this proposal, linguists and psychologists have noted that we often talk about the abstract in terms of the relatively concrete. For example, people tend to talk about time in terms of space. In English, we use expressions like 'putting the past *behind* us', 'proposing theories *ahead* of their time', and 'looking *forward* to the future'. Spatial metaphors for time are highly systematic within languages, and are pervasive across languages (Alverson, 1994; Boroditsky, 2001; Clark, 1973; Gentner, 2001; Tversky, Kugelmass, & Winter, 1991). Do spatiotemporal metaphors reveal something fundamental about the our temporal representations? It is tempting to infer from these patterns in language that our conception of time is somehow grounded in our conception of space, but this would be scientifically imprudent. The fact that we talk about time using spatial words does not entail that we think about time using spatial representations. Nonlinguistic evidence is needed to elucidate the relationship between space and time in the human mind.

In the present study, we investigated spatial and temporal representations using simple psychophysical tasks with nonlinguistic stimuli and responses. Subjects estimated either the duration or the spatial displacement of stimuli presented on a computer screen. In the first experiment, subjects viewed lines that 'grew' horizontally across the screen from left to right, and disappeared as soon as they reached their maximum displacement. Line durations and displacements were varied orthogonally, so there was no correlation between the spatial and temporal components of the stimuli. As such, one stimulus dimension served as a distractor for the other: an irrelevant bit of information that could potentially interfere with task performance. Patterns of cross-dimensional interference were analyzed to reveal relationships between our representations of space and time.

Space and time are asymmetrically dependent in linguistic metaphors: we tend to talk about time in terms of space more than we talk about space in terms of time (Boroditsky, 2000; Clark, 1973; Gentner, 2001). Are mental representations of space and time also asymmetrically dependent? In English, we often use words that quantify spatial displacement (e.g., a *long* line, a *short* rope) in order to talk about the duration of an event (e.g., a *long* meeting, a *short* concert). Is it possible that people use representations of spatial displacement in order to think about duration? We hypothesized that if mental representations of time depend on mental representations of space, but not the other way around, then any cross-dimensional interference observed during subjects' behavioral responses would be *asymmetric*: line displacement would affect estimates of line duration more than line duration affected estimates of line displacement. Alternatively, if spatial and temporal representations are mutually interdependent, then cross-dimensional interference should be approximately *symmetric*: line displacement should modulate subjects' estimates of line duration, and vice-versa. If spatial and temporal representations are *independent*, then no significant cross-dimensional interference should be found.

Experiment 1: Growing Lines

Experiment 1 investigated whether cross-dimensional interference would be detected in subjects' estimates of the duration or the displacement of moving stimuli, and whether any observed interference of one domain on the other would be symmetric or asymmetric.

Methods

Participants 9 native English speakers from the MIT community participated in these studies in exchange for payment.

Materials Lines were presented on a computer monitor (resolution=1024x768 pixels, dpi=72). Durations ranged from 1000 milliseconds to 5000 milliseconds in 500 millisecond increments. Displacements ranged from 200 to 800 pixels in 75 pixel increments. Nine durations were fully crossed with nine displacements to produce 81 distinct line types. Lines 'grew' horizontally across the screen one pixel at a time, from left to right along the vertical midline, at rates ranging from 40 pixels/second to 800 pixels/second. Lines started growing 112 pixels from the left edge of the monitor on average, but the starting point of each line was jittered with respect to the average starting point (+/- up to 50 pixels), so that the monitor would not provide a reliable spatial frame of reference. Each line remained on the screen until its maximum displacement was reached.

Procedure Participants viewed 162 growing lines, one line at a time. The word "ready" appeared in the center of an otherwise blank screen for two seconds immediately before each line was shown. Immediately after each line, a prompt appeared in either the upper left or lower left corner of the screen indicating that the subject should reproduce either the line's displacement (if an 'X' icon appeared), or its duration (if an 'hourglass' icon appeared). Space trials and time trials were randomly intermixed.

To estimate displacement, subjects clicked the mouse once on the center of the X, moved the mouse in a straight line to the right, and clicked the mouse a second time to indicate they had traversed a distance equal to the maximum displacement of the stimulus. Whereas stimuli grew from a jittered starting point on the vertical midline of the screen, responses were initiated at a fixed starting point in either the upper or lower left corner. Thus, the response was translated both vertically and horizontally with respect to the stimulus. To estimate duration, subjects clicked the mouse once on the center of the hourglass icon, waited the appropriate amount of time, and clicked again in the same spot, to indicate the time it took for the stimulus to reach its maximum displacement.

All responses were self-paced. Importantly, for a given trial, subjects reproduced either the displacement or the duration of the stimulus, never both. Response data were collected for both the trial-relevant and the trial-irrelevant stimulus dimension, to ensure that subjects were following instructions.

Results and Discussion

Results show a strong cross-dimensional effect of displacement on duration estimation, but no significant effect of duration on displacement estimation (figure 1a-b). For stimuli of the same average duration, lines that traveled a shorter distance were judged to take a shorter time, and lines that traveled a longer distance were judged to take a longer time. Subjects incorporated irrelevant spatial information in their temporal estimates, but not vice-versa. This behavioral asymmetry was predicted based on the asymmetric relationship between time and space in linguistic metaphors. Overall, subjects' estimates of duration and displacement were highly accurate, and about equally accurate across the two domains (figure 1c-d). The asymmetric cross-dimensional interference we observe cannot be attributed to a difference between the accuracy of subjects' duration and displacement estimations, as no significant difference was found.

Since speed and displacement were positively correlated in our experimental design, it was important to distinguish their effects on time estimation. A post-hoc analysis showed that the effect of line displacement on estimated duration remained highly significant when the effects of line speed and target duration were controlled ($r=0.14$; $df=725$; $p<0.0001$). In contrast, the effect of speed on duration estimation was not significant when the effects of target duration and target displacement were controlled ($r= -0.02$; $df=725$; *ns*).

Experiment 2: Growing Lines, Selective Attention

What was the source of this cross-dimensional confusion? In Experiment 1, subjects did not know until immediately after each line was presented whether they would need to estimate displacement or duration. It was important for them to attend to both spatial and temporal information, and to update both types of information online throughout the stimulus presentation. If subjects were told ahead of time whether they would need to estimate a line's displacement or its duration, would the cross-dimensional interference disappear? Experiment 2 addressed this possibility. Subjects were informed immediately before each line appeared which stimulus dimension they would need to estimate. Thus, subjects had the opportunity to selectively attend to the trial-relevant stimulus dimension, and if possible, to ignore the trial-irrelevant dimension.

Methods

Participants 9 native English speakers from the MIT community participated in this study in exchange for payment.

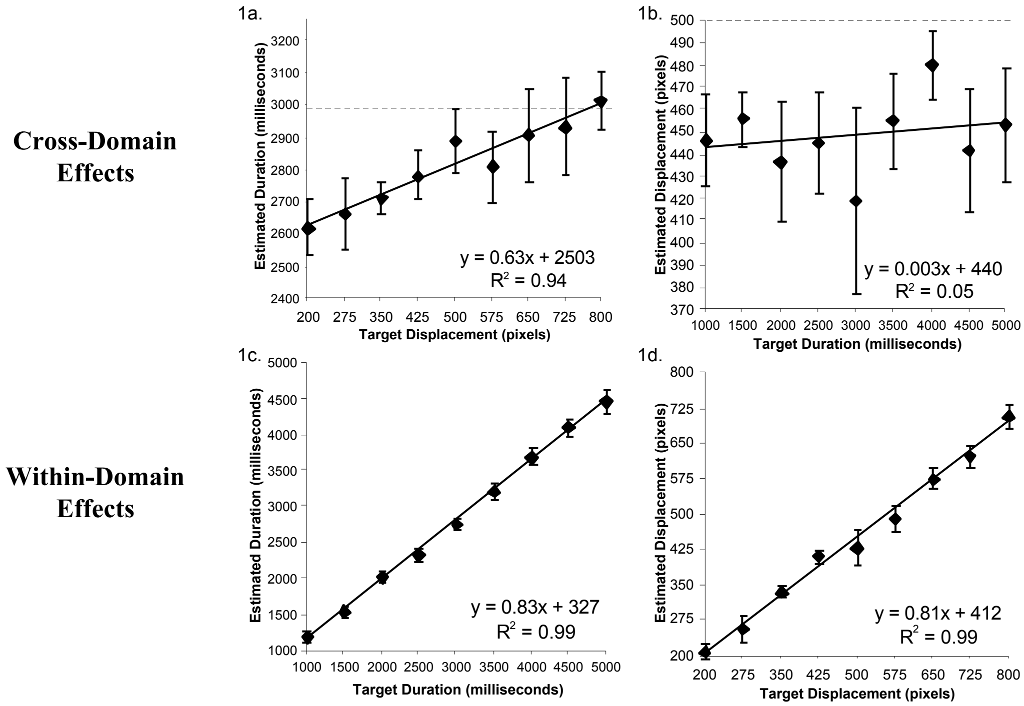

Figure 1. Grand averaged duration and displacement estimates for Experiment 1. Top: Cross-domain effects. 1a. (left) Effect of displacement on duration estimation. 1b. (right) Effect of duration on displacement estimation. Horizontal dotted lines indicate mean target duration in 1a., and mean target displacement in 1b. The scales of the ordinates of 1a. and 1b. are proportionate to one another with respect to the total range of target durations and displacements. Bottom: Within-domain effects. 1c. (left) Effect of target duration in on estimated duration. 1d. (right) Effect of target displacement on estimated displacement.

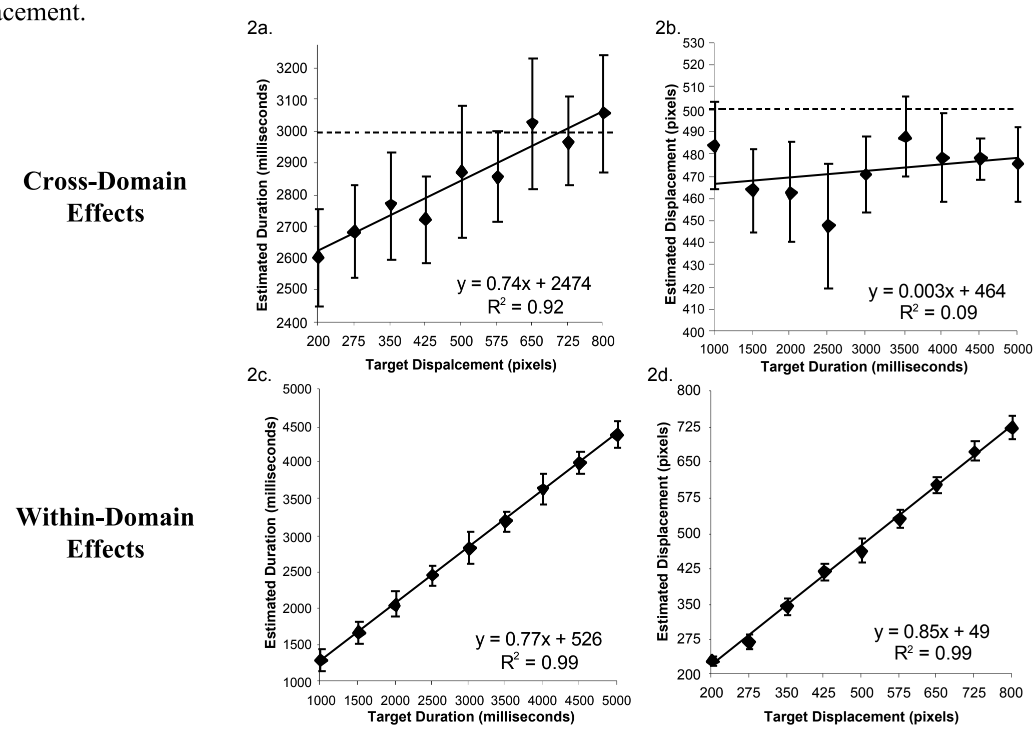

Figure 2. Grand averaged duration and displacement estimates for Experiment 2. Top: Cross-domain effects. 2a. (left) Effect of displacement on duration estimation. 2b. (right) Effect of duration on displacement estimation. Horizontal dotted lines indicate mean target duration in 2a., and mean target displacement in 2b. The scales of the ordinates of 2a. and 2b. are proportionate to one another with respect to the total range of target durations and displacements. Bottom: Within-domain effects. 2c. (left) Effect of target duration in on estimated duration. 2d. (right) Effect of target displacement on estimated displacement.

Materials and Procedure Stimulus materials were identical to those used in Experiment 1. The procedure was also identical, with one exception. In Experiment 1, the word "ready" appeared in the middle of an otherwise blank screen for two seconds immediately preceding each line stimulus. In Experiment 2, the word "ready" was replaced either by the word "space" next to an X icon, or by the word "time" next to an hourglass icon. These words and symbols indicated whether the subject would need to estimate the displacement or the duration of the next line. Line stimuli, prompts, and responses were exactly as in Experiment 1, thus all stimuli and responses remained entirely nonlinguistic.

Results and Discussion

Results of Experiment 2 replicate those of Experiment 1. Subjects were able to disregard line duration when estimating displacement. In contrast, subjects appeared unable to ignore line displacement, even when they were encouraged to selectively attend to duration (figure 2a-d). The cross-dimensional effect of space on time in Experiment 1 was not induced by a task-specific demand for subjects to encode spatial and temporal information simultaneously.

Response data collected for the trial-irrelevant dimension confirm that subjects understood the task, and were not explicitly confusing displacement with duration (i.e., Ss were not giving a spatial response when they were supposed to give a temporal response).

Experiment 3: Temporal Frame of Reference

Several follow-up experiments were conducted to corroborate the results of Experiments 1 and 2, to assess their generality, and to evaluate potential explanations. One concern was that subjects may have relied on spatial information to make temporal estimates because stimuli were situated in a constant spatial frame of reference (i.e., the computer monitor). For experiment 3, stimuli were also situated in a constant temporal frame of reference. Delay periods were introduced preceding and following line presentations, which were proportional to the gaps between the ends of the stimulus lines and the edges of the monitor.

Methods

Participants 9 native English speakers from the MIT community participated in this study in exchange for payment.

Materials and Procedure Stimulus materials and procedures were identical to those used in experiment 2, with the following exception. The interval between the disappearance of the ready screen and the appearance of the response prompt did not vary with stimulus duration as in previous experiments, rather it was fixed at 6400 milliseconds. Stimuli were preceded and followed by a delay period, which was proportional to spatial gap separating the ends of the line stimuli from the left and right edges of the monitor.

Results and Discussion

The cross-dimensional effects found in Experiments 1 and 2 remained qualitatively unchanged in Experiment 3 (figure 3c).

Experiment 4: Reverse Lines

In the first three experiments, lines grew from left to right, consistent with the direction of reading and writing in English, and the direction of increase in many graphs . Is it possible that we learn an association between progress in space and time through the habit of scanning across the printed page, and that this association contributes to the observed cross-dimensional interference? For Experiment 4, lines grew from right to left. If habitual reading/writing direction were responsible for the positive association between spatial input and temporal estimation in the previous experiments, then a negative association between stimulus displacement and estimated duration would be expected in the present experiment.

Methods

Participants 12 native English speakers from the MIT community participated in this study in exchange for payment.

Materials and Procedure Stimulus materials and procedures were identical to those used in experiment 2, with the following exceptions. Whereas lines grew from left to right in experiment 2, they grew from right to left in experiment 4. Displacement estimations were made by moving the mouse from right to left.

Results and Discussion

Results showed that as before, duration estimations varied positively as a function of line displacement, whereas displacement estimations did not vary significantly as a function of line duration (figure 3d). Since the asymmetric dependence of temporal estimation on spatial input can be demonstrated whether lines grow from left to right or from right to left, it is unlikely that this effect arises from our experience of reading text or interpreting graphs.

Experiment 5: Moving Dot

Was the visual percept of a long line necessary to lengthen subjects' temporal estimates, or would a more abstract experience of displacement suffice? Experiment 5 addressed this question. Rather than viewing a growing line, subjects viewed a moving dot. Whereas the spatial extent of a line stimulus could be perceived directly, the extent of a dot's path had to be imagined. In order to compute the distance that a dot traveled, subjects had to retrieve the dot's starting point from memory once its ending point was reached.

Methods

Participants 10 native English speakers from the MIT community participated in this study in exchange for payment.

Materials and Procedure Stimulus materials and procedures were identical to those used in experiment 2, with the following exceptions. Rather than viewing a growing line, subjects viewed a dot which moved horizontally across the midline of the screen from left to right.

Results and Discussion

Results showed a strong and asymmetric dependence of time on space (figure 3e), suggesting that subjects' abstract representations of displacement were sufficient to modulate temporal estimates.

Experiment 6: Stationary Lines

How might this relationship between distance and duration arise? One possibility is that we are sensitive to the correlation of displacement and duration in our everyday experience with moving objects: any change in an object's position is necessarily accompanied by a change in time. Spatial change may serve as an index of temporal change, which we use because motion through space is more directly perceptible than motion through time. Experiments 1-5 used moving stimuli. Would the asymmetric relationship between space and time be found if static stimuli were used? In Experiment 6, subjects viewed stationary lines of various lengths, which remained on the screen for various durations, according to the parameters used in the original growing line experiments. It was predicted that the effect of displacement on duration estimation would be mitigated, since spatial and temporal changes are correlated in our experience of moving objects, but not stationary objects.

Methods

Participants 22 native English speakers from the MIT community participated in this study in exchange for payment.

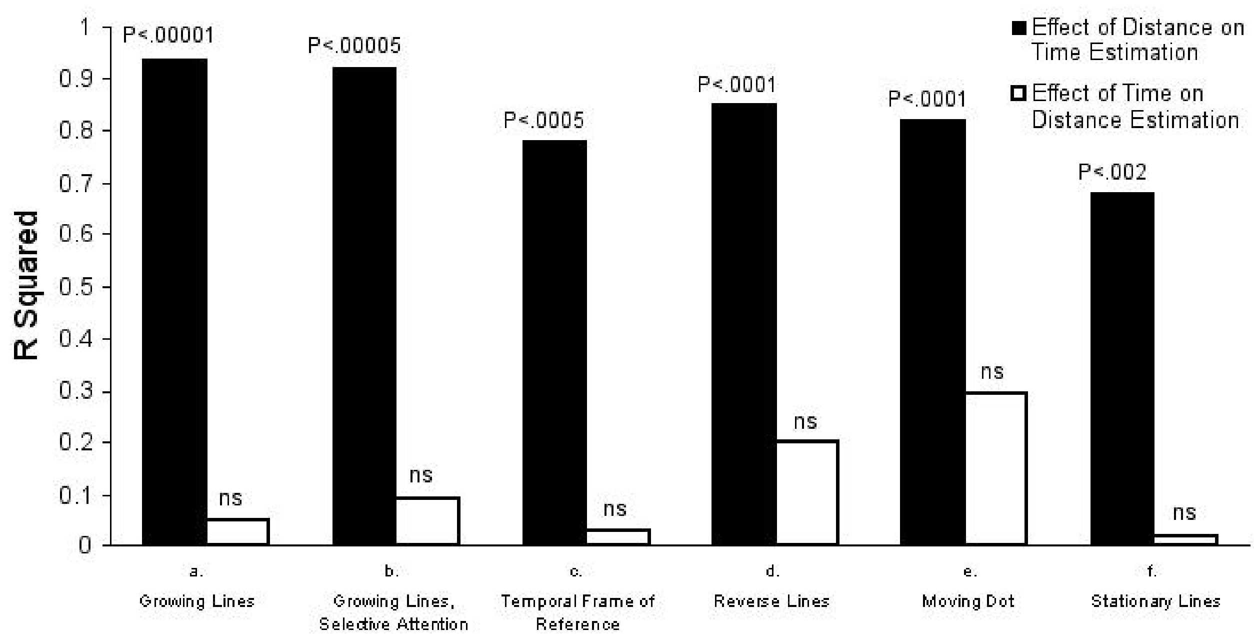

Figure 3. Summary of cross-dimensional interference effects. The effect of distance on time estimation was significantly greater than the effect of time on distance estimation for all experiments. (Fig. 3a, Growing lines: difference of correlations=0.75; z= 3.24, $p<0.001$. Fig. 3b, Growing lines, selective attention: difference of correlations=0.66; z=2.84, $p<0.01$. Fig. 3c, Growing lines, temporal frame of reference: difference of correlations=0.71; z=2.09, $p<0.02$. Fig. 3d, Growing lines, reverse direction: difference of correlations=0.47; z= 1.91, $p<0.03$. Fig. 3e, Moving dot: difference of correlations=1.11; z= 2.52, $p<0.01$. Fig. 3f, Stationary lines: difference of correlations=0.69; z=1.78, $p<0.04$.)

Materials and Procedure Stimulus materials and procedures were identical to those used in experiment 2, with the following exception. Rather than viewing moving lines, subjects viewed stationary lines of various lengths, which remained on the screen for various durations, according to the parameters used in experiment 2.

Results and Discussion

Results showed the same pattern of cross-dimensional interference found in all previous experiments (figure 3f). Subjects' time estimates were asymmetrically dependent on stimulus displacement, even in the absence of stimulus motion. Notably, however, the effect of displacement on time estimation was significantly weaker in Experiment 6 than in the comparable experiment that used moving lines (difference of slopes=0.44; t= 4.00; df=14; p<0.002).

General Discussion and Conclusions

When Piaget (1927/1969) investigated kids' reasoning about space and time, he found that children often based their judgments of duration on their experience of displacement. For example, when asked to judge the relative duration of two trains traveling along parallel tracks, kids often reported (erroneously) that the train that went the longer distance took the longer time. Piaget concluded that children could not reliably distinguish the spatial and temporal components of moving stimuli until about age nine. Like many contemporary results in cognitive science, our findings suggest that Piaget was right about the phenomenon he observed, but wrong about the age at which kids resolve their confusion: apparently MIT undergraduates cannot reliably distinguish the spatial and temporal components of their experience, either.

Together, Experiments 1- 6 demonstrate that we rely on spatial information to make temporal estimates, particularly when space and time are conflated in motion. Conversely, these experiments provide no evidence that we use temporal information to make spatial estimates. This behavioral asymmetry reflects the directionality of spatiotemporal metaphors in language, and suggests that the metaphoric relationship between time and space is not just linguistic, it is also conceptual. Not only do we talk about time in terms of space, we also think about time using spatial representations. Time is only one of the domains that we spatialize in language: musical pitches can be *high* or *low*, numbers can be *large* or *small*, hopes and expectations can *rise* or *fall*. Further experiments are needed to explore the possibility that domains other than time are also conceptually grounded in space, and to determine whether spatial metaphors in language simply mirror underlying conceptual structures, or whether language plays a role in shaping relationships between spatial representations and abstract thought.

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References

Alverson, H. (1994). *Semantics and Experience: Universal Metaphors of Time in English, Mandarin, Hindi, and Sesotho*. Baltimore: Johns Hopkins University Press.

Boroditsky, L. (2000). Metaphoric structuring: understanding time through spatial metaphors. *Cognition, 75*(1), 1-28.

Boroditsky, L. (2001). Does language shape thought? Mandarin and English speakers' conceptions of time. *Cognit Psychol, 43*(1), 1-22.

Boroditsky, L., & Ramscar, M. (2002). The Roles of Body and Mind in Abstract Thought. *Psychological Science, 13*(2), 185-189.

Clark, H. H. (1973). Space, Time, Semantics and the Child. In T. E. Moore (Ed.), *Cognitive Development and the Acquisition of Language* (pp. 27-63). New York: Academic Press.

Emmory, K. (Ed.). (2001). *Space on hand: the exploitation of signing space to illustrate abstract thought*. Cambridge: MIT Press.

Gattis, M. (Ed.). (2001). *Space as a Basis for Abstract Thought*. Cambridge: MIT Press.

Gentner, D. (Ed.). (2001). *Spatial Metaphors in Temporal Reasoning*. Cambridge: MIT Press.

Gibbs, R. W., jr. (1994). *The poetics of mind: Figurative thought, language, and understanding.* Cambridge: Cambridge University Press.

Goldstone, R., & Barsalou, L. (1998). Reuniting perception and conception. *Cognition, 65*, 231-262.

Lakoff, G., & Johnson, M. (1980). *Metaphors We Live By*. Chicago: University of Chicago Press.

Lakoff, G., & Johnson, M. (1999). *Philosophy in the flesh: The embodied mind and its challenge to Western thought*. Chicago: University of Chicago Press.

Piaget, J. (1927/1969). *The Child's Conception of Time*. New York: Ballantine Books.

Pinker, S. (1989). *Learnability and cognition: The acquisition of argument structure*. Cambridge, MA, US: MIT Press.

Pinker, S. (1997). *How the mind works*. New York: Norton.

Talmy, L. (1988). Force Dynamics in Language and Cognition. *Cognitive Science, 12*, 49-100.

Tversky, B., Kugelmass, S., & Winter, A. (1991). Cross-cultural and developmental trends in graphic productions. *Cognitive Psychology, 23*, 515-557.