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17 Space for thinking

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1 Introduction

How do people think about things they can never see or touch? The ability to invent and reason about domains such as time, ideas, or mathematics is uniquely human, and is arguably the hallmark of human sophistication. Yet, how people mentally represent these abstract domains has remained one of the mysteries of the mind. This chapter explores a potential solution: perhaps the mind recruits old structures for new uses. Perhaps sensory and motor representations that result from physical interactions with the world (e.g., representations of physical space) are recycled to support abstract thought. This hypothesis is motivated, in part, by patterns observed in language: in order to talk about abstract things, speakers often recruit metaphors from more concrete or perceptually rich domains. For example, English speakers often talk about time using spatial language (e.g., a *long* vacation; a *short* meeting). Cognitive linguists have argued such expressions reveal that people conceptualize abstract domains like time metaphorically, in terms of space (see Lakoff and Johnson, 1999; c.f., Evans, 2004). Although linguistic evidence for Metaphor Theory is abundant, the necessary nonlinguistic evidence has long been elusive; people may *talk* about time using spatial words, but how can we know whether people really *think* about time using mental representations of physical space?

This chapter describes a series of experiments that evaluate Metaphor Theory as an account of the evolution and structure of abstract concepts and explore relations between language and nonlinguistic thought, using the abstract domain of time and the relatively concrete domain of space as a testbed. Hypotheses about the way people mentally represent space and time were based on patterns in metaphorical language, but were tested using simple psychophysical tasks with nonlinguistic stimuli and responses. Results of the first set of experiments showed that English speakers incorporate irrelevant spatial information into their estimates of time (but not vice versa), suggesting that people not only talk about time using spatial language, but also think about time using spatial representations. The second set of experiments showed that (a) speakers of different languages rely on different spatial metaphors for duration, (b) the dominant metaphor in participants' first languages strongly predicts their performance on nonlinguistic time estimation tasks, and (c) training participants to use new spatiotemporal metaphors in language changes the way they estimate time. A final set of experiments extends the experimental techniques developed to explore mental representations of time to the domain of musical pitch. Together, these studies demonstrate that the metaphorical language people use to describe abstract ideas provides a window on their underlying mental representations, and also shapes those representations. The structure of abstract

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domains such as time appears to depend, in part, on both linguistic experience and on physical experience in perception and motor action.

1.1 Time as an abstract domain

> *For what is time? Who can readily and briefly explain this? Who can even in thought comprehend it, so as to utter a word about it?*
>
> *If no one asks me, I know: if I wish to explain it to one who asketh, I know not.*
>
> Saint Augustine, *Confessions*, Book 11

How long will it take you to read this chapter? The objective time, as measured by the clock, might depend on whether you're scrutinizing every detail, or just skimming to get the main ideas. The subjective time might vary according to physiological factors like your pulse and body temperature (Cohen, 1967; Ornstein, 1969), psychological factors like how much the text engages your interest and attention (Glicksohn, 2001; James, 1890; Zakay and Block, 1997), and some surprising environmental factors like the size of the room you're sitting in (DeLong, 1981).

Although subjective duration is among the earliest topics investigated by experimental psychologists (Mach, 1886), the cognitive sciences have yet to produce a comprehensive theory of how people track the passage of time, or even to agree on a set of principles that consistently govern people's duration estimates. An excerpt from a review by Zakay and Block (1997) illustrates the current state of confusion:

> People may estimate filled durations as being longer than empty durations, but sometimes the reverse is found. Duration judgments tend to be shorter if a more difficult task is performed than if an easier task is performed, but again the opposite has also been reported. People usually make longer duration estimates for complex than for simple stimuli, although some researchers have found the opposite. (pg. 12)

What makes time perception so difficult to understand? Ornstein (1969) argues that although we *experience* the passage of time, the idea that time can be *perceived* through the senses is misleading (cf. Evans, 2004):

> One major reason for the continuing scattering of [researchers'] effort has been that time is treated as if it were a sensory process. If time were a sensory process like vision…we would have an 'organ' of time experience such as the eye. (pg. 34)

Although time is not something we can see or touch, we often talk about it as if it were (Boroditsky, 2000; Clark, 1973; Gruber, 1965; Jackendoff, 1983; Lakoff and Johnson, 1980). Consider the following pair of sentences:

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i) They moved the truck forward two meters.

ii) They moved the meeting forward two hours.

The truck in sentence i is a physical object which can move forward through space, and whose motion we might see, hear, or feel, from the staring point to the ending point. By contrast, there is no literal motion described in sentence ii. The meeting is not translated through space, and there is no way to experience its 'movement' through time via the senses. Events that occur in time are more abstract than objects that exist in space insomuch as we typically have richer perceptual evidence for the spatial than for the temporal.[1]

In this chapter, I will argue that (a) the language people typically use to talk about duration reveals important links between the abstract domain of time and the relatively concrete domain of space, (b) people use spatial representations to conceptualize time even when they're not using language, and (c) although the domains of space and time provide a particularly useful testbed for hypotheses about the evolution and structure of abstract concepts, *time* is only one of many abstract domains of knowledge that depend, in part, on perceptuo-motor representations built up via experience with the physical world.

1.2 Metaphor and the problem of abstract thought

The mystery of how people come to mentally represent abstract domains such as time, ideas, or mathematics has engaged scholars for centuries, sometimes leading to proposals that seem unscientific by modern standards. Plato (*Meno*, ca. 380 B.C.E.) argued that we cannot acquire abstract concepts like *virtue* through instruction, and since babies are not born knowing them, it must be that we recover such concepts from previous incarnations of our souls. Charles Darwin contended that evolution can explain the emergence of abstract thought without recourse to reincarnation, yet it is not immediately obvious how mental capacities that would have been superfluous for our Pleistocene forebears could have been selected for. What selection pressures could have resulted in our ability to compose symphonies, invent calculus, or imagine time travel? How did foragers become physicists in an eyeblink of evolutionary time? The human capacity for abstract thought seems to far exceed what could have benefited our predecessors, yet natural selection can only effect changes that are immediately useful. The apparent superfluity of human intelligence drove Alfred Wallace, Darwin's co-founder of the theory of evolution by natural selection, to abandon their scientific theory and invoke a divine creator to explain our capacity for abstract thought (Darwin, 1859/1998, 1874/1998; Gould, 1980; Pinker, 1997; Wallace, 1870/2003).[2]

Darwin's own formulation of evolutionary theory points toward an elegant potential solution to Wallace's dilemma: sometimes organisms recycle old structures for new uses. An organ built via selection for a specific role may be fortuitously suited to perform other unselected roles, as well. For example, the fossil record suggests that feathers were not

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originally 'designed' for flying. Rather, they evolved to regulate body temperature in small running dinosaurs, and were only later co-opted for flight (Gould, 1991). The process of adapting existing structures for new functions, which Darwin (1859/1993) gave the misleading name *preadaptation*, was later dubbed *exaptation* by evolutionary biologist Steven Jay Gould and colleagues (1982). Gould argued that this process may explain the origin of many biological and psychological structures that direct adaptation cannot.

Are abstract concepts like dinosaur feathers? Can exaptation account for mental abilities in humans that could not have been selected for directly? If so, how might this have happened: which *ad*apted capacities might abstract domains be *ex*apted from? Steven Pinker (1997) sketched the following proposal:

> Suppose ancestral circuits for reasoning about space and force were copied, the copies' connections to the eyes and muscles were severed, and references to the physical world were bleached out. The circuits could serve as a scaffolding whose slots are filled with symbols for more abstract concerns like states, possessions, ideas, and desires. (pg. 355)

As evidence that abstract domains arose from circuits designed for reasoning about the physical world, Pinker appeals to patterns observed in language. Many linguists have noted that when people talk about states, possessions, ideas, and desires, they do so by co-opting the language of intuitive physics (Clark, 1973, Gibbs, 1994; Gruber, 1965; Jackendoff, 1983; Lakoff and Johnson, 1980; Langacker, 1987; Talmy, 1988). In particular, words borrowed from physical domains of space, force, and motion, give rise to linguistic metaphors for countless abstract ideas. For each pair of expressions below, *l* illustrates a literal use and *m* a metaphorical use of the italicized words.

1*l* a *high* shelf
1*m* a *high* price

2*l* a *big* building
2*m* a *big* debate

3*l* *forcing* the door
3*m* *forcing* the issue

4*l* *pushing* the button
4*m* *pushing* the limit

5*l* *keeping* the roof *up*
5*m* *keeping* appearances *up*

The concrete objects described in the literal sentences (e.g., shelf, building, door, button, roof) belong to a different ontological category than the abstract entities in the metaphorical examples, according a test of what physical relations they can sensibly be said to enter into. For example, it is sensible to say 'the cat sat on the shelf / building / door

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/ button / roof', but it may not be sensible to say that 'the cat sat on the price / debate / issue / limit / appearance'. This test is similar to a test of sensible predicates for concrete vs. abstract entities devised by Fred Sommer (1963; cf., Turner, 2005).

Based on examples like these, linguists have argued that people create abstract domains by importing structure from concepts grounded in physical experience. Although anticipated by others (e.g., Lafargue, 1898/1906), this idea appears to have been first articulated as the Thematic Relations Hypothesis (TRH) in 1965, by Jeffery Gruber. TRH was later elaborated by Jackendoff (1972; 1983) who wrote:

> The psychological claim behind [Gruber's linguistic discovery] is that the mind does not manufacture abstract concepts out of thin air…it adapts machinery that is already there, both in the development of the individual organism and in the evolutionary development of the species. (1983, pg. 188–9)

Not all theorists agree on the significance of metaphorical language for theories of mental representation. Gregory Murphy (1996; 1997) raised concerns about both the vagueness of the psychological processes suggested by linguists and about the limitations of purely linguistic evidence for metaphorical conceptual structure. Murphy (1996) proposed that linguistic metaphors may merely reveal similarities between mental domains: not causal relationships. Across languages, people may use the same words to talk about space and time because these mental domains are structurally similar, and are therefore amenable to a common linguistic coding. He argued that in the absence of corroborating nonlinguistic evidence, his *Structural Similarity* proposal should be preferred on grounds of simplicity. His view posits that all concepts are represented independently, on their own terms, whereas the metaphorical alternative posits complex concepts that are structured interdependently. It is evident that people *talk* about abstract domains in terms of relatively concrete domains, but do they really *think* about them that way?

1.3 From conceptual metaphor to mental metaphor

The idea that conventionalized metaphors in language reveal the structure of abstract concepts is often associated with Conceptual Metaphor theory, proposed by linguist George Lakoff and philosopher Mark Johnson (1980, 1999). Lakoff and Johnson described 'conceptual metaphors' as one of 'three major findings of cognitive science' (1999, pg. 3). Yet, their claim that people *think* metaphorically was supported almost entirely by evidence that we *talk* metaphorically. Despite the impressive body of linguistic theory and data that Lakoff and Johnson summarized (and the corroborating computational models of word meaning), they offered little evidence that the importance of metaphor extends beyond language. In the absence of nonlinguistic evidence for metaphorically structured mental representations, the idea that abstract thought is an exaptation from physical domains remained 'just an avowal of faith' among scientists who believe that the mind must ultimately be explicable as a product of natural selection (Pinker, 1997, pg. 301).

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The term 'conceptual metaphor' is used ambiguously, sometimes to refer to patterns in language, and other times to nonlinguistic conceptual structures that are hypothesized to underlie these patterns in language. To avoid this ambiguity, I will refer to patterns in language as *linguistic metaphors* and to the hypothesized nonlinguistic metaphorical structures in the mind as *mental metaphors* (Casasanto, 2008, 2009a). This terminological shift allows several critical questions to be framed clearly. Part 1 of this chapter will address the question, 'Do people use mental metaphors that correspond to their linguistic metaphors in order to conceptualize abstract domains, even when they're not using language?' Part 2 asks, 'If so, do people who tend to use different linguistic metaphors also rely on different mental metaphors?' and further, 'Does using different linguistic metaphors *cause* speakers of different languages to rely on different mental metaphors?' Finally, distinguishing linguistic metaphors from mental metaphors allows us to pose other questions that lie beyond the scope of this chapter (see Casasanto, 2008, 2009a, 2009b), such as, 'Are there any mental metaphors for which no corresponding linguistic metaphors exist?' This question has received virtually no attention from linguists or psychologists. This could be due, in part, to the fact that it is nonsensical when phrased in the traditional terminology: 'Are there any conceptual metaphors for which no corresponding conceptual metaphors exist?' Whereas Conceptual Metaphor theorists treat patterns in language as a source of *evidence* that people think metaphorically, the research presented here takes patterns in language as a source of *hypotheses* about conceptual structure.

1.3 Experimental evidence for mental metaphors

Boroditsky (2000) conducted some of the first behavioral tests of the psychological reality of mental metaphors. Her tasks capitalized on the fact that in order to talk about spatial or temporal sequences, speakers must adopt a particular frame of reference. Sometimes we use expressions that suggest we are moving through space or time (e.g., *we're approaching Maple Street*; *we're approaching Christmas*). Alternatively, we can use expressions that suggest objects or events are moving with respect to one another (*Maple Street comes before Elm Street*; *Christmas comes before New Year's*). In one experiment, Boroditsky found that priming participants to adopt a given spatial frame of reference facilitated their interpretation of sentences that used the analogous temporal frame of reference. Importantly, the converse was not found: temporal primes did not facilitate interpreting spatial sentences. This priming asymmetry parallels a well established asymmetry in linguistic metaphors: people talk about the abstract in terms of the concrete (e.g., time in terms of space) more than the other way around (Lakoff and Johnson, 1980). Based on these results Boroditsky proposed a refinement of Conceptual Metaphor Theory, the Metaphoric Structuring View, according to which (a) the domains of space and time share conceptual structure, and (b) spatial information is useful (though not necessary) for thinking about time. A second set of experiments showed that real-world spatial situations (e.g., riding on a train, or standing in a cafeteria line) and even imaginary spatial scenarios can influence how people interpret spatiotemporal metaphors

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(Boroditsky and Ramscar, 2002). These studies rule out what Boroditsky (2000) calls the Dubious View, that space-time metaphors in language are simply 'etymological relics with no psychological consequences' (pg. 6).

If people use spatial schemas to think about time, as suggested by metaphors in language, then do people who use different spatiotemporal metaphors in their native tongues think about time differently? To find out, Boroditsky (2001) compared performance on space-time priming tasks in speakers of English, a language which typically describes time as horizontal, and speakers of Mandarin Chinese, which also commonly uses vertical spatiotemporal metaphors. English speakers were faster to judge sentences about temporal succession (e.g., *March comes earlier than April*) when primed with a horizontal spatial event, but Mandarin speakers were faster to judge the same sentences when primed with a vertical spatial stimulus. This was true despite the fact that all of the sentences were presented in English. In a follow-up study, Boroditsky (2001) trained English speakers to use vertical metaphors for temporal succession (e.g., *March is <u>above</u> April*). After training, their priming results resembled those of the native Mandarin speakers.

Together, Boroditsky's studies provide some of the first evidence that (a) people not only talk about time in terms of space, they also think about it that way, (b) people who use different spatiotemporal metaphors also think about time differently, and (c) learning new spatial metaphors can change the way you mentally represent time. Yet, these conclusions are subject to a skeptical interpretation. Boroditsky's participants made judgments about sentences containing spatial or temporal language. Perhaps their judgments showed relations between spatial and temporal thinking that were consistent with linguistic metaphors only because they were required to process space or time *in language.* Would the same relationships between mental representations of space and time be found if participants were tested on nonlinguistic tasks?

The fact that people communicate via language replete with anaphora, ambiguity, metonymy, sarcasm, and deixis seems proof that what we say provides only a thumbnail sketch of what we think. Most theorists posit at least some independence between semantic representations and underlying conceptual representations (Jackendoff, 1972; Katz and Fodor, 1963; Levelt, 1989; cf., Fodor, 1975). Even those who posit a single, shared 'level' of representation for linguistic meaning and nonlinguistic concepts allow that semantic structures must constitute only a subset of conceptual structures (Chomsky, 1975; Jackendoff, 1983). Because we may think differently when we're using language and when we're not, well-founded doubts persist about how deeply patterns in language truly reflect – and perhaps shape – our nonlinguistic thought. According to linguist Dan Slobin (1996):

> Any utterance is a selective schematization of a concept – a schematization that is in some ways dependent on the grammaticized meanings of the speaker's particular language, recruited for the purposes of verbal expression. (pg. 75–76)

Slobin argues that when people are 'thinking for speaking' (and presumably for reading or listening to speech), their thoughts are structured, in part, according to their language

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and its peculiarities. Consequently, speakers of different languages may think differently when they are using language. But how about when people are not thinking for speaking? Eve Clark (2003) asserts that:

> [When people are] thinking for remembering, thinking for categorizing, or one of the many other tasks in which we may call on the representations we have of objects or events – then their representations may well include a lot of material not customarily encoded in their language. It seems plausible to assume that such conceptual representations are nearer to being universal than the representations we draw on for speaking. (pg. 21)

Clark predicts that results may differ dramatically between tests of language–thought relations that use language and those that do not:

> …we should find that in tasks that require reference to representations in memory that don't make use of any linguistic expression, people who speak different languages will respond in similar, or even identical, ways. That is, representations for nonlinguistic purposes may differ very little across cultures or languages. (2003, pg. 22)

Clark adds:

> Of course, finding the appropriate tasks to check on this without any appeal to language may prove difficult. (2003, pg. 22)

Clark's skepticism echoes concerns raised by Papafrougou, Massey, and Gleitman (2002) regarding the difficulty of studying the language–thought interface:

> …domains within which language might interestingly influence thought are higher–level cognitive representations and processes, for instance, the linguistic encoding of time […] A severe difficulty in investigating how language interfaces with thought at these more 'significant' and 'abstract' levels has been their intractability to assessment. As so often, the deeper and more culturally resonant the cognitive or social function, the harder it is to capture it with the measurement and categorization tools available to psychologists. (pg. 191–192)

For the studies reported here, new experimental tools were developed in order to (a) evaluate Metaphor Theory as an account of the structure and evolution of abstract concepts, and (b) investigate relationships between language and nonlinguistic mental representations. The first two sets of experiments used the concrete domain of space and the relatively abstract domain of time as a testbed for Metaphor Theory, and the final set extended these findings beyond the domain of time. These experiments used novel psychophysical tasks with nonlinguistic stimuli and responses in order to distinguish two theoretical positions, one which posits *shallow* and the other *deep* relations between language and nonlinguistic thought (table 1):

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Table 1.

The Shallow View:	The Deep View:
i. Language reflects the structure of the mental representations that speakers form for the purpose of using language. These are likely to be importantly different, if not distinct, from the representations people use when they are thinking, perceiving, and acting without using language.	**i.** Language reflects the structure of the mental representations that speakers form for the purpose of using language. These are likely to be similar to, if not overlapping with, the representations people use when they are thinking, perceiving, and acting without using language.
ii. Language may influence the structure of mental representations, but only (or primarily) during language use.	**ii.** Patterns of thinking established during language use may influence the structure of the mental representations that people form even when they're not using language.
iii. Cross-linguistic typological differences are likely to produce 'shallow' behavioral differences on tasks that involve language or high-level cognitive abilities (e.g., naming, explicit categorization). However, such behavioral differences should disappear when subjects are tested using nonlinguistic tasks that involve low-level perceptuo-motor abilities.	**iii.** Some cross-linguistic typological differences are likely to produce 'deep' behavioral differences, observable not only during tasks that involve language or high-level cognitive abilities, but also when subjects are tested using nonlinguistic tasks that involve low-level perceptuo-motor abilities.
iv. Although the semantics of languages differ, speakers' underlying conceptual and perceptual representations are, for the most part, universal.	**iv.** Where the semantics of languages differ, speakers' underlying conceptual and perceptual representations may differ correspondingly, such that language communities develop distinctive conceptual repertoires.

2 Do people use space to think about time?

Do people use mental representations of space in order to mentally represent time, as metaphors in language suggest they do – even when they're not using language? The first six experiments reported here tested the hypothesis that temporal thinking depends, in part, on spatial thinking (Casasanto and Boroditsky, 2008). In each task, participants viewed simple nonlinguistic, non-symbolic stimuli (i.e., lines or dots) on a computer screen, and estimated either their duration or their spatial displacement. Durations and displacements were fully crossed, 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 piece of information that could potentially interfere with task performance. Patterns of cross-dimensional interference were analyzed to reveal relationships between spatial and temporal representations.[3]

Broadly speaking, there are three possible relationships between people's mental representations of space and time. First, the two domains could be *symmetrically dependent*. John Locke (1689/1995) argued that space and time are mutually inextricable in our minds, concluding that, 'expansion and duration do mutually embrace and comprehend each other; every part of space being in every part of duration, and every part of duration in every part of expansion' (p. 140). Alternatively, our ideas of space and time could be

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independent. Any apparent relatedness could be due to structural similarities between essentially unrelated domains (Murphy, 1996, 1997). A third possibility is that time and space could be *asymmetrically dependent*. Representations in one domain could be parasitic on representations in the other, as suggested by their asymmetric relationship in linguistic metaphors (Boroditsky, 2000; Gentner, 2001; Gibbs, 1994; Lakoff and Johnson, 1980, 1999).

These three possible relationships between space and time predict three distinct patterns of cross-dimensional interference. If spatial and temporal representations are symmetrically dependent on one another, then any cross-dimensional interference should be approximately symmetric: line displacement should modulate estimates of line duration, and vice versa. Alternatively, if spatial and temporal representations are independent, there should be no significant cross-dimensional interference. However, if mental representations of time are asymmetrically dependent on mental representations of space, as suggested by spatiotemporal metaphors in language, then any cross-dimensional interference should be asymmetric: line displacement should affect estimates of line duration more than line duration affects estimates of line displacement.

For Experiment 1, native English speaking participants viewed 162 lines of varying lengths (200–800 pixels, in 50 pixel increments), presented on a computer monitor for varying durations (1–5 seconds, in 500 ms increments). Lines 'grew' horizontally from left to right, one pixel at a time, along the vertical midline. Each line remained on the screen until it reached its maximum displacement, and then disappeared. Immediately after each line was shown, a prompt appeared indicating that the participant should reproduce either the line's displacement (if an 'X' icon appeared) or its duration (if an 'hourglass' icon appeared), by clicking the mouse to indicate the endpoints of each temporal or spatial interval. Space trials and time trials were randomly intermixed.

Results of Experiment 1 showed that spatial displacement affected estimates of duration, but duration did not affect estimates of spatial displacement (Figure 1a). For stimuli of the same average duration, lines that travelled a shorter distance were judged to take a shorter time, and lines that travelled a longer distance were judged to take a longer time. Subjects incorporated irrelevant spatial information into their temporal estimates, but not vice versa. Estimates of duration and displacement were highly accurate, and were equally accurate in the two domains. The asymmetric cross-dimensional interference we observe cannot be attributed to a difference in the accuracy of duration and displacement estimations, as no significant difference in was found.

Experiments were conducted to assess the generality of these results, and to evaluate potential explanations. In Experiment 1, participants did not know until after each line was presented whether they would need to estimate displacement or duration. They had to attend to both the spatial and temporal dimensions of the stimulus. Experiment 2 addressed the possibility that cross-dimensional interference would diminish if participants were given the opportunity to attend selectively to the trial-relevant stimulus dimension, and to ignore the trial-irrelevant dimension. Materials

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and procedures were identical to those used in Experiment 1, with one exception. A cue preceded each growing line, indicating which stimulus dimension participants would need to reproduce. Results of Experiment 2 (Figure 1b) replicated those of Experiment 1. Participants were able to disregard line duration when estimating displacement. By contrast, they were unable to ignore line displacement, even when they were encouraged to attend selectively to duration. The cross-dimensional effect of space on time estimation in Experiment 1 was not caused by a task-specific demand for subjects to encode spatial and temporal information simultaneously.

Experiments 3–5 addressed concerns that spatial information in the stimulus may have been more stable or more salient than temporal information, and that differences in stability or salience produced the asymmetrical cross-dimensional interference observed in Experiments 1 and 2. One concern was that participants 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. Temporal delay periods were introduced preceding and following line presentations, which were proportional to the spatial gaps between the ends of the stimulus lines and the edges of the monitor. Results (Figure 1c) replicated those of Experiments 1 and 2.

Experiment 4 addressed the possibility that space would no longer influence participants' time estimates if stimulus duration were indexed by something non-spatial. For this experiment, a constant tone (260 Hz) accompanied each growing line. Materials and procedures were otherwise identical to those used in Experiment 2. The tone began sounding when the line started to grow across the screen, and stopped sounding when the line disappeared. Thus, stimulus duration was made available to the participant in both the visual and auditory modalities, but stimulus displacement was only available visually. Results (Figure 1d) replicated those of the previous experiments. Displacement strongly influenced participants' duration estimates, even when temporal information was provided via a different sensory modality from the spatial information.

Experiment 5 was designed to equate the mnemonic demands of the spatial and temporal dimensions of the stimulus. Materials and procedures were identical to those used in Experiment 2, with one exception. Rather than viewing a growing line, subjects viewed a dot (10x10 pixels) that moved horizontally across the midline of the screen. In the previous experiments, just before each growing line disappeared participants could see its full spatial extent, from end to end, seemingly at a glance. By contrast, the spatial extent of a moving dot's path could never be seen all at once, rather it had to be imagined: in order to compute the distance that a dot travelled, participants had to retrieve the dot's starting point from memory once its ending point was reached. The spatial and temporal dimensions of the dot stimulus had to be processed similarly in this regard: whenever we compute the extent of a temporal interval we must retrieve its starting point from memory once the end of the interval is reached. Results (Figure 1e) replicated those of previous experiments.

Experiment 6 investigated whether motion or speed affected participants' time estimates in Experiments 1–5, rather than stimulus displacement. Materials and procedures were identical to those used in Experiment 2, with the following exception.

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Rather than growing lines, participants viewed stationary lines, and estimated either the amount of time they remained on the screen or their distance from end to end, using mouse clicks. Results replicate those of previous five experiments (Figure 1f), indicating that stimulus displacement can strongly modulate time estimates even in the absence of stimulus motion.

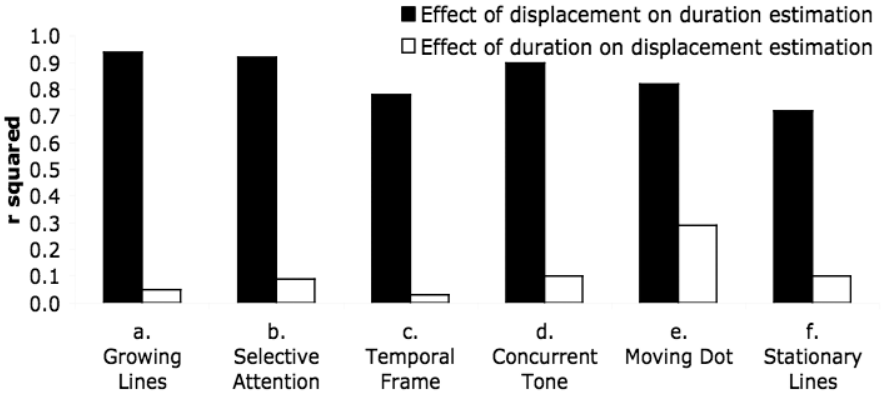

Figure 1. Summary of cross-dimensional interference effects for Experiments 1–6. The effect of distance on time estimation was significantly greater than the effect of time on distance estimation for all experiments. (1a, Growing lines: difference of correlations = 0.75; $z = 3.24$, $p <.001$. 1b, Growing lines, selective attention: difference of correlations = 0.66; $z = 2.84$, $p < .003$. 1c, Growing lines, temporal frame of reference: difference of correlations = 0.71; $z =2.09$, $p <.02$. 1d, Growing lines, concurrent tone: difference of correlations =0.63; $z = 2.60$, $p <.005$. 1e, Moving dot: difference of correlations = 1.45; $z = 3.69$, $p <.001$. 1f, Stationary lines: difference of correlations = 0.54; $z = 1.62$, $p <.05$.) Figure reproduced with permission from Casasanto, D. and Boroditsky, L. (2008). Time in the Mind: Using space to think about time. *Cognition, 106, 579–593.*

Results of all six experiments unequivocally support the hypothesis that people incorporate spatial information into their time judgments more than they incorporate temporal information into their spatial judgments. These findings converge with those of Cantor and Thomas (1977), who showed that spatial information influences temporal judgments but not vice versa for very briefly presented stimuli (30–70 msecs). Previous behavioral tests of Metaphor Theory have used linguistic stimuli (Boroditsky, 2000, 2001; Boroditsky and Ramscar, 2002; Gibbs, 1994; Meier and Robinson, 2004; Meier, Robinson and Clore, 2004; Richardson, Spivey, Barsalou and McRae, 2003; Schubert, 2005; Torralbo, Santiago and Lupiáñez, 2006). While these studies support the psychological reality of mental metaphors, they leave open the possibility that people only think about abstract domains like time metaphorically when they are using language (i.e., when they are 'thinking for speaking' (E. Clark, 2003; Slobin, 1996)). Experiments described above used nonlinguistic stimuli and responses, and demonstrated for the first time that even our low-level perceptuo-motor representations in the domains of space and time are related as predicted by linguistic metaphors.

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Although English speakers describe time in terms of space almost obligatorily (Jackendoff, 1983; Pinker, 1997), we can also optionally describe space in terms of time. For example, in English we could say *my brothers live* 5 *minutes apart* to indicate that they live a short distance apart. Thus, the relationship between time and space in linguistic metaphors is asymmetrical, but not unidirectional. Accordingly, asymmetrical cross-dimensional interference between space and time was predicted in these experiments. This prediction does not entail that time can never affect spatial judgments: only that the effect of space on time estimation should be greater than the effect of time on space estimation when the effects are compared appropriately. Results of Experiments 1–6 did not show any significant effect of time on distance estimation, but such a finding would still be compatible with the asymmetry hypothesis, so long as the effect of distance on time estimation was significantly greater than the effect of time on distance estimation.

It is noteworthy that space influenced temporal judgments even for spatiotemporal stimuli that participants could experience directly. Growing lines are observable, and are arguably less abstract than entities like the 'moving meeting' described in section 0.1. Brief durations could, in principle, be mentally represented independently of space, by an interval-timer or pulse-accumulator (see Ivry and Richardson, 2002 for review), yet these data suggest that spatial representations are integral to the timing of even simple, observable events. Thinking about time metaphorically in terms of space may allow us to go beyond these basic temporal representations. Mentally representing time as a linear path may enable us to conceptualize more abstract temporal events that we cannot experience directly (e.g., moving a meeting *forward* or pushing a deadline *back*), as well as temporal events that we can never experience at all (e.g., the *remote* past or the *distant* future). Metaphorical mappings from spatial paths, which can be traveled both forward and backward, may give rise to temporal constructs such as *time–travel* that only exist in our imagination.

Together, these experiments demonstrate that the metaphors we use can provide a window on the structure of our abstract concepts. They also raise a further question about relations between linguistic metaphors and nonlinguistic mental representations: if people think about time in terms of space (the way they talk about it), then do people who use different space-time metaphors in their native languages think differently – even when they're not using language?

3 Does language shape the way we think about time?

The first set of experiments supports the *Deep View* of language-thought relations by showing that temporal representations depend, in part, on spatial representations, as predicted by metaphors in English – even when people are performing low-level, nonlinguistic psychophysical tasks (see Table 1, number i). However, it is not clear from these data whether linguistic metaphors merely reflect English speakers' underlying nonlinguistic representations of time, or whether language also shapes those representations. According to the *Shallow View,* it is possible that speakers of a language with

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different duration metaphors would nevertheless perform similarly to English speakers on nonlinguistic tasks. Thus, the first set of experiments leaves the following question unaddressed, posed by the influential amateur linguist, Benjamin Whorf:

> Are our own concepts of 'time', 'space', and 'matter' given in substantially the same form by experience to all men, or are they in part conditioned by the structure of particular languages?' (1939/2000, pg. 138.)

This *Whorfian* question remains the subject of renewed interest and debate. Does language shape thought? The answer *yes* would call for a reexamination of the 'universalist' assumption that has guided Cognitive Science for decades, according to which nonlinguistic concepts are formed independently of the words that name them, and are invariant across languages and cultures (Fodor, 1975; Pinker, 1994, Papafragou, Massey and Gleitman, 2002). This position is often attributed to Chomsky (1975), but has been articulated more recently by Pinker (1994) and by Lila Gleitman and colleagues (Papafragou, Massey and Gleitman, 2002; Snedeker and Gleitman, 2004). The Shallow View proposed here can be considered a variety of the universalist view that can still plausibly be maintained despite recent psycholinguistic evidence supporting the Whorfian hypothesis (e.g., Boroditsky, 2001).

Skepticism about some Whorfian claims has been well founded (see Pinker, 1994, ch. 3, for a review of evidence against the Whorfian hypothesis). A notorious fallacy, attributable in part to Whorf, illustrates the need for methodological rigor. Whorf (1939/2000) argued that Eskimos must conceive of snow differently than English speakers because the Eskimo lexicon contains multiple words that distinguish different types of snow, whereas English has only one word to describe all types. The exact number of snow words the Eskimos were purported to have is not clear. This number has now been inflated by the popular press to as many as four hundred. According to a Western Greenlandic Eskimo dictionary published in Whorf's time, however, Eskimos may have had as few as two distinct words for snow (Pullum, 1991).

Setting aside Whorf's imprecision and the media's exaggeration, there remains a critical missing link between Whorf's data and his conclusions: Whorf (like many researchers today) used purely linguistic data to support inferences about nonlinguistic mental representations. Steven Pinker illustrates the resulting circularity of Whorf's claim in this parody of his logic:

> [They] speak differently so they must think differently.
> How do we know that they think differently?
> Just listen to the way they speak! (Pinker, 1994, pg. 61).

Such circularity would be escaped if nonlinguistic evidence could be produced to show that two groups of speakers who talk differently also think differently in corresponding ways.

A series of experiments explored relationships between spatiotemporal language and nonlinguistic mental representation of time. The first experiment, a corpus search, uncovered previously unexplored cross-linguistic differences in spatial metaphors for

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duration. Next, we tested whether these linguistic differences correlate with differences in speakers' low-level, nonlinguistic time representations.[4] Finally, we evaluated a causal role for language in shaping time representations.[5]

3.1 1-Dimensionsal and 3-dimensional spatial metaphors for time

Literature on how time can be expressed verbally in terms of space (and by hypothesis, conceptualized in terms space) has focused principally on linear spatial metaphors. But is time necessarily conceptualized in terms of unidimensional space? Some theorists have suggested so (Clark, 1973, Gentner, 2001), and while this may be true regarding temporal succession, linguistic metaphors suggest an alternative spatialization for duration. English speakers not only describe time as a line, they also talk about *oceans of time, saving time in a bottle*, and liken the 'days of their lives' to *sands through the hourglass*. Quantities of time are described as amounts of a substance occupying three dimensional space (i.e., volume).

Experiment 7 compared the use of 'time as distance' and 'time as amount' metaphors across four languages. Every language we examined uses both distance and amount metaphors, but their relative prevalence and productivity appear to vary markedly. In English, it is natural to talk about *a long time*, borrowing the structure and vocabulary of a linear spatial expression like *a long rope.* Yet in Spanish, the direct translation of 'long time', *largo tiempo*, sounds awkward to speakers of most dialects.[6] *Mucho tiempo*, which means 'much time', is preferred.

In Greek, the words *makris* and *kontos* are the literal equivalents of the English spatial terms *long* and *short*. They can be used in spatial contexts much the way *long* and *short* are used in English (e.g., *ena <u>makry</u> skoini* means 'a <u>long</u> rope'). In temporal contexts, however, *makris* and *kontos* are dispreferred in instances where *long* and *short* would be used naturally in English. It would be unnatural to translate *a <u>long</u> meeting* literally as *mia <u>makria</u> synantisi*. Rather than using distance terms, Greek speakers typically indicate that an event lasted a long time using *megalos*, which in spatial contexts means physically 'large' (e.g., a big building), or using *poli*, which in spatial contexts means 'much' (e.g., much water). Compare how English (*e*) and Greek (*g*) typically modify the duration of the following events (literal translations in parentheses):

1*e* long night
1*g* megali nychta (*big night*)

2*e* long relationship
2*g* megali schesi (*big relationship*)

3*e* long party
3*g* parti pou kratise poli (*party that lasts much*)

4*e* long meeting
4*g* synantisi pou diekese poli (*meeting that lasts much*)

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In examples 1*g* and 2*g*, the literal translations might surprise an English speaker, for whom *big night* is likely to mean 'an exciting night', and *big relationship* 'an important relationship'. For Greek speakers, however, these phrases can also communicate duration, expressing time not in terms of 1-dimensional linear space, but rather in terms of 3-dimensional size or amount.

To quantify the relative prevalence of distance and amount metaphors for duration across languages, the most natural phrases expressing the ideas 'a long time' and 'much time' were elicited from native speakers of English (*long time, much time*), French (*longtemps, beaucoup de temps*), Greek (*makry kroniko diastima*, *poli ora*), and Spanish (*largo tiempo, mucho tiempo*). The frequencies of these expressions were compared in a very large multilingual text corpus: www.google.com. Each expression was entered as a search term. Google's language tools were used to find exact matches for each expression, and to restrict the search to web pages written only in the appropriate languages. The number of google 'hits' for each expression was tabulated, and the proportion of distance hits and amount hits was calculated for each pair of expressions, as a measure of their relative frequency. English and French, distance metaphors were dramatically more frequent than amount metaphors. The opposite pattern was found in Greek and Spanish (Figure 2).

Although all languages surveyed use *both* distance and amount metaphors for duration, the relative strengths of these metaphors appears to vary across languages. This simple corpus search by no means captures all of the complexities of how time is metaphorized in terms of space within or between languages, but these findings corroborate native speakers' intuitions for each language, and provide a quantitative linguistic measure on which to base predictions about behavior in nonlinguistic tasks.

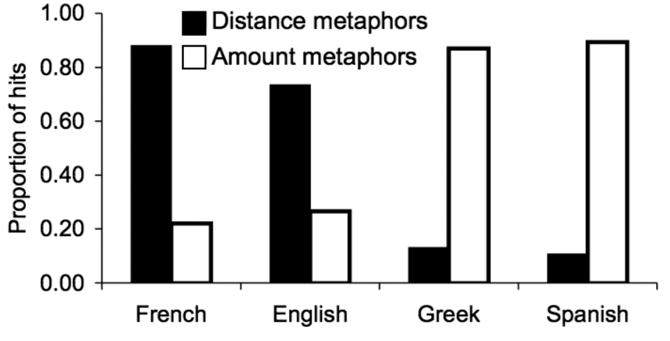

Figure 2. Results of Experiment 7. Black bars indicate the proportion of Google 'hits' for expressions meaning *long time*, and white bars for expressions meaning *much time* in each language.

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3.2 Do people who talk differently think differently?

Do people who use different spatiotemporal metaphors think about time differently – even when they're not using language? Experiments 8 and 9 explored the possibility that speakers who preferentially use distance metaphors in language tend to co-opt linear spatial representations to understand duration, whereas speakers who preferentially use amount metaphors tend to co-opt 3-dimensional spatial representations. Speakers of two languages surveyed in Experiment 7 (i.e., English and Greek) performed a pair of nonlinguistic psychophysical tasks, which required them to estimate duration while overcoming different kinds of spatial interference (i.e., distance or amount interference). If people's conceptions of time are substantially the same universally irrespective of the languages they speak, as suggested by the *Shallow View*, then performance on these tasks should not differ between language groups. On the *Deep View*, however, it was predicted that participants' performance should vary in ways that parallel the metaphors in their native languages.

The 'distance interference' task was modeled on the 'growing line' task described in Experiment 2. English participants in the previous growing line studies may have suffered interference from distance during duration estimation, in part, because distance and duration are strongly conflated in the English lexicon. Would the same confusion be found in speakers of other languages? It was predicted that native English speakers would show a strong effect of distance on time estimation when performing the growing line task, whereas speakers of Greek would show a weaker effect, since distance and duration are less strongly associated in the Greek language .

A complementary 'amount interference' task was developed, in which participants watched a schematically drawn container of water filling up gradually, and estimated either how full it became or how much time it remained on the computer screen, using mouse clicks as in the growing line tasks. Spatial and temporal parameters of the stimuli were equated across tasks. Behavioral predictions for the Filling Tank task were the mirror image of predictions for the Growing Line task: speakers of Amount Languages like Greek should show a strong influence of 'fullness' on time estimation, whereas speakers of Distance Languages like English should show a weaker effect.

Results showed that effects of spatial interference on duration estimation followed predictions based on the relative prevalence of distance and amount metaphors for time in speakers' native languages. English showed a strong effect of line length but a weak effect of tank fullness on duration estimation; Greek speakers showed the opposite pattern of results (Figure 3). A 2 x 2 ANOVA compared these slopes with Language (English, Greek) and Task (distance interference, amount interference) as between-subject factors, revealing a highly significant Language by Task interaction, with no main effects ($F(1,56)=10.41$, $p=.002$).

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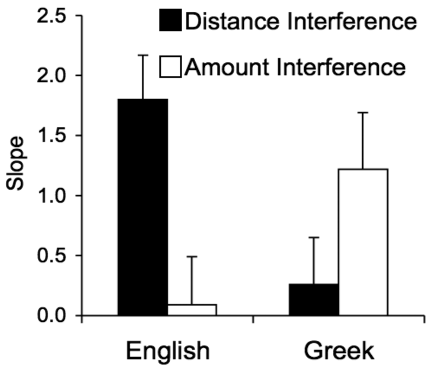

Figure 3. Results of Experiments 8 and 9. Black bars indicate the slope of the effect of line displacement on duration estimation. White bars indicate the slope of the effect of tank fullness on duration estimation. The relationship between the effects of distance and volume on time estimation was predicted by the relative prevalence of distance and amount metaphors in English and Greek (see figure 2).

The observed differences in the effects of spatial distance and amount on duration estimation cannot be attributed to overall differences in performance across tasks or across groups. Within-domain performance (i.e., the effect of target duration on estimated duration, and the effect of target distance or fullness on estimated distance or fullness) was compared across tasks and across groups: no significant differences were found between correlations or slopes, even in pairwise comparisons.

One difference between the Growing Line and Filling Tank tasks was that the lines grew horizontally, but the tanks filled vertically. To determine whether the spatial orientation of the stimuli and responses gave rise to the observed cross-linguistic differences in performance on the Growing Lines and Filling Tank tasks, an Upward Growing Lines task was administered to speakers of English and Greek. No significant difference was found in the effect of vertical displacement on time estimation across languages, suggesting that the orientation of stimuli cannot account for the between-group differences observed in Experiments 8 and 9.

Overall, Experiments 7–9 show that the way people talk about time correlates strongly with the way they think about it – even when they're performing simple nonlinguistic perceptuo-motor tasks – as predicted by the *Deep View* of language-thought relations. (See Table 1, ii.- iv.) Much of the literature on temporal language has highlighted crosslinguistic commonalities in spatiotemporal metaphors (e.g., Alverson, 1994). The studies presented here begin to explore some previously neglected crosslinguistic differences, and to discover their nonlinguistic consequences. The corpus search reported in Experiment 7 provides one measure of how frequently different languages use distance and amount metaphors for duration; the relative frequencies of *long time* and *much time* expressions across languages proved highly predictive of performance on nonlinguistic duration estimation tasks. Often, however, spatial metaphors describe *events* rather than describing *time*, per se. Preliminary data from a questionnaire study

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suggest that English consistently prefers distance metaphors for describing both time (e.g., *a long time*) and events (e.g., *a long party*), whereas Greek consistently prefers volume metaphors for time (e.g., *poli ora* tr.'much time') and for events (e.g., *parti pou kratise poli* tr. 'party that lasts much'), corroborating the results of the corpus search. Ongoing studies seek to characterize these crosslinguistic differences more fully, and to specify which features of language correspond to 'deep' differences in nonlinguistic mental representations of time.

3.3 How might perceptual and linguistic experience shape abstract thought?

How do people come to think about time in terms of space? How do speakers of different languages come to conceptualize time differently? Turning to the first question, some mappings from concrete to abstract domains of knowledge may be initially established pre-linguistically, based on interactions with the physical world (Clark, 1973). For example, people are likely to track the kinds of correlations in experience that are important for perceiving and acting on their environment; they may learn associations between time and space by observing that more time passes as objects travel farther, and as substances accumulate more. This proposal entails that although time depends in part on spatial representations, time can also be mentally represented *qua* time, at least initially: in order for cross-dimensional associations to form, some primitive representations must already exist in each dimension. Primitive temporal notions, however, of the sort that we share with infants and non-human animals, may be too vague or fleeting to support higher order reasoning about time. Grafting primitive temporal representations onto spatial representations may make time more amenable to verbal or imagistic coding, and may also import the inferential structure of spatial relations into the domain of time (Pinker, 1997).

If metaphorical mappings are experience-based, and are established pre-linguistically, what role might language play in shaping abstract thought? Since the laws of physics are the same in all language communities, prelinguistic children's conceptual mappings between time, distance, and amount could be the same universally. Later, as children acquire language, these mappings are adjusted: each time we use a linguistic metaphor, we activate the corresponding conceptual mapping. Speakers of Distance Languages then activate the time-distance mapping frequently, eventually strengthening it at the expense of the time-amount mapping (and vice versa for speakers of Amount Languages). Mechanistically, this could happen via a process of competitive associative learning.

Did language experience give rise to the language-related differences in performance reported for the Growing Line and Filling Tank experiments? A perennial complaint about studies claiming effects of language on thought is that researchers mistake correlation for causation. Although it is difficult to imagine what nonlinguistic cultural or environmental factors could have caused performance on Experiments 8 and 9 in English and Greek speakers to align so uncannily with the metaphors in these languages, the data are nevertheless correlational. Using crosslinguistic data to test for a causal

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influence of language on thought is problematic, since experimenters cannot randomly assign subjects to have one first language or another: crosslingusitic studies are necessarily quasi-experimental.

For Experiment 10, a pair of training tasks (i.e., true experimental interventions) was conducted to provide an in principle demonstration that language can influence even the kinds of low-level mental representations that people construct while performing psychophysical tasks, and to test the hypothesis that language shapes time representations in natural settings by adjusting the strengths of cross-domain mappings. Native English speakers were randomly assigned to perform either a Distance Training or Amount Training task. Participants completed 192 fill-in-the-blank sentences using the words *longer* or *shorter* for Distance Training, and *more* or *less* for the Amount Training task. Half of the sentences compared the length or capacity of physical objects (e.g., An alley is *longer / shorter* than a clothesline; A teaspoon is *more / less* than an ocean), the other half compared the duration of events (e.g., A sneeze is *longer / shorter* than a vacation; A sneeze is *more / less* than a vacation). By using distance terms to compare event durations, English speakers were reinforcing the already preferred source-target mapping between distance and time. By using amount terms, English speakers were describing event durations similarly to speakers of an Amount Language (see Greek examples in section 2.1), and by hypothesis, they were activating the dispreferred volume-time mapping. After this linguistic training, all participants performed the nonlinguistic Filling Tank task from Experiment 9. We predicted that if using a linguistic metaphor activates the corresponding conceptual mapping between source and target domains, then repeatedly using amount metaphors during training should (transiently) strengthen participants' nonlinguistic amount-time mapping.

Consistent with this prediction, the slope of the effect of amount on time estimation was significantly greater after amount training than after distance training (difference of slopes = 0.89, $t(28) = 1.73$, $p<.05$; Figure 4). Following about 30 minutes of concentrated usage of amount metaphors in language, native English speakers' performance on the Filling Tank task was statistically indistinguishable from the performance of the native Greek speakers tested in Experiment 9. By encouraging the habitual use of either distance- or amount-based mental metaphors, our experience with natural language may influence our everyday thinking about time in much the same way as this laboratory training task.

These findings help to resolve apparent tensions between the proposal that perceptuo-motor image schemas underlie our abstract concepts and the notion of linguistic relativity. Johnson (2005) defines an image schema as 'a dynamic recurring pattern of organism-environment interactions' (pg. 19). Presumably, people from all language communities inhabit the same physical world and interact with their environment using the same perceptuo-motor capacities, therefore the image schemas they develop should be universal. Yet, even if we all develop similar image schemas initially, based on our physical experiences, Experiments 8–10 suggest the way we deploy these image schemas depends on our linguistic experiences. Duration can be mentally represented *both* in terms of distance and in terms of amount. The extent to which each of these conceptual space-time mappings is activated in a given speaker or community of speakers varies

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with the strength of the corresponding linguistic metaphors. The structure of abstract concepts like *duration* appears to be shaped both by perceptuo-motor experience (which is plausibly universal) and by language use (which is culture-specific).

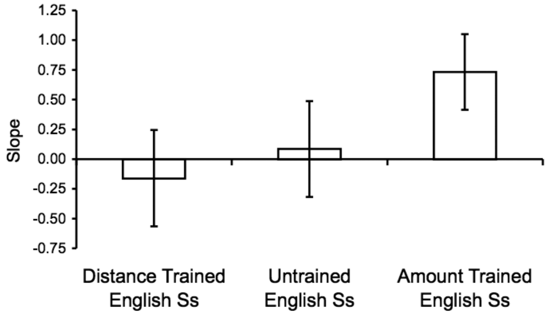

Figure 4. Results of Experiment 10. Bars indicate the slope of the effect of tank fullness on duration estimation after training with distance metaphors (left), amount metaphors (right), or with no training (middle) prior to performing the Filling Tank task. The cross-dimensional effect of amount on time estimation was significantly greater after training with amount metaphors than with distance metaphors.

4 Beyond space and time: Spatial representation of musical pitch

Time and space provide a model system for exploring connections between abstract and concrete mental representations, but time is just one among many domains that we spatialize in language; time may be just one of many abstract domains that import their structure or content, in part, from the domain of space. In Experiment 11, the psychophysical tasks that were developed to investigate space and time were adapted to explore relationships between space and musical pitch.[7]

Like time, pitch is often described in English using linear spatial terms. Unlike time, pitch tends to be described using vertical rather than horizontal metaphors. Pitches can be *high* or *low*, and can *rise*, *fall*, *soar*, or *dip below* the staff. Yet, the fact that we talk about pitch in terms of vertical space doesn't necessarily mean that we think about it that way. One possibility is that pitch is mentally represented on its own terms, and is only coded into the same words that we use to describe space as a matter of convenience: domains that share structural similarities may be amenable to common linguistic description, obviating multiple domain-specific vocabularies. Alternatively, the spatialization of pitch in language may serve as a clue that leads us to a fuller understanding of how pitch is mentally represented.

The 'growing line' task described in Experiment 2 was modified for a nonlinguistic test of the hypothesis that our mental representations of musical pitch depend, in part, on spatial representations. Nine displacements ranging from 100 to 500 pixels (in 50 pixel increments) were fully crossed with nine different pitches ranging from middle

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C4 to G#4 (in semitone increments). For each trial, participants heard a constant pitch while watching a line grow up the screen from bottom to top (for half of the subjects) or across the screen from left to right (for the other half of the subjects). Before each stimulus, participants were informed whether they would need to estimate distance or pitch, to encourage them to attend to the trial-relevant stimulus dimension and, if possible, to ignore the trial-irrelevant dimension. Participants estimated line displacements using mouse clicks, as in previous experiments. To estimate pitch, participants used the mouse to adjust a probe tone until it matched the remembered target pitch.

Watching vertical lines significantly modulated subjects' pitch estimates: tones of the same average frequency were judged to be higher in pitch if they accompanied lines that grew higher on the screen (effect of actual distance on estimated pitch: slope=.37; r^2=.77, p<.003). By contrast, watching horizontal lines did not significantly modulate pitch estimates. This finding is consistent with the occurrence of vertical but not horizontal metaphors for pitch in English. Further analyses showed that whereas vertical displacement affected estimates of pitch, pitch did not significantly influence estimates of vertical displacement. Thus, the relation between nonlinguistic mental representations of space and pitch appears to be asymmetrical, as predicted by the directionality of space-pitch metaphors in language.

While these results support the claim that musical pitch is mentally represented in part metaphorically, in terms of vertical space, they are agnostic as to the direction of causation between language and thought. Further studies (such as those described in sections 2.1–2.3) are needed to investigate whether linguistic metaphors merely reflect the spatial schemas that partly constitute pitch representations, or whether the way we talk about pitch can also shape the way we think about it.

5 Conclusions

Direct evidence that spatial cognition supported the evolution of abstract concepts may forever elude us, because human history cannot be recreated in the laboratory, and the mind leaves no fossil record. However, the studies reported here demonstrate the importance of spatial representations for abstract thinking in the mind that evolution produced. For decades, inferences about the perceptual foundations of abstract thought rested principally on linguistic and psycholinguistic data. These psychophysical experiments show that even nonlinguistic representations in concrete and abstract domains are related as linguistic metaphors predict: we think in mental metaphors.

Together, the experiments described in this chapter suggest that people not only talk about abstract domains using spatial words, they also think about them using spatial representations. Results are incompatible with the *Shallow View* of language-thought relations, and provide some of the first evidence for the view that language has *Deep* influences on nonlinguistic mental representation (see table 1). Experiments 1–6 show that people use spatial representations to think about time even when they're not producing or understanding language. Experiments 7–9 show that people who talk differently about time also think about it differently, in ways that correspond to their

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language-particular metaphors. Experiment 10 shows that language not only reflects the structure of underlying mental representations, it can also shape those representations in ways that influence how people perform even low-level, nonlinguistic, perceptuo-motor tasks. Experiment 11 shows that these findings extend beyond the 'testbed' domains of space and time.

These findings are difficult to reconcile with a universalist position according to which language calls upon nonlinguistic concepts that are presumed to be 'universal' (Pinker, 1994, pg. 82) and 'immutable' (Papafragou, Massey and Gleitman, 2002, pg. 216). Beyond influencing *thinking for speaking* (Slobin, 1996), language can also influence the nonlinguistic representations we build for remembering, acting on, and perhaps even perceiving the world around us. It may be universal that people conceptualize time according to the spatial metaphors, but since these metaphors vary across languages, members of different language communities develop distinctive conceptual repertoires. The structure of abstract domains like time depends, in part, on both perceptuo-motor experience and on experience using language.

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Notes

1 Like our mental representations of time, some of our spatial representations may also be quite abstract. For example, our conception of the Milky Way galaxy's breadth is no more grounded in direct experience than our conception of its age.

2 Cultural evolution alone cannot explain our capacity for abstract thought because, as Wallace noted, members of 'stone age' societies who were given European educations manifested abilities to similar those of modern Europeans: the latent capacity to read, to perform Western art music, etc. was present in the minds of people whose cultures had never developed these abstract forms of expression.

3 Experiments 1–6 are described in full in Casasanto, D. and Boroditsky, L. (2008). Time in the mind: Using space to think about time. *Cognition* 106: 579–593.

4 A preliminary report on Experiments 7–9 appeared in Casasanto, D., Boroditsky, L., Phillips, W., Greene, J., Goswami, S., Bocanegra-Thiel, S., Santiago-Diaz, I., Fotokopoulu, O., Pita, R. and Gil, D. (2004). *How deep are effects of language on thought? Time estimation in speakers of English, Indonesian, Greek, and Spanish*. Proceedings of the 26th Annual Conference of the Cognitive Science Society, Chicago, IL.

5 A preliminary report on Experiment 10 appeared in Casasanto, D. (2005) *Perceptual foundations of abstract thought*. Doctoral dissertation, MIT.

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6 Native speakers of European and South American Spanish report that *largo tiempo* is only used in poetic contexts (e.g., the Peruvian national anthem) to mean 'throughout the length of history'. By contrast, some bilingual North American Spanish speakers report that *largo tiempo* can be used colloquially, much like long time, perhaps because the construction is imported from English.

7 A preliminary report on Experiment 11 appeared in Casasanto, D., W. Phillips and L. Boroditsky, *Do we think about music in terms of space: Metaphoric representation of musical pitch*. Proceedings of 25th Annual Conference of the Cognitive Science Society, 2003. Boston, MA.

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