

Space and Time in the Child's Mind: Evidence for a Cross-Dimensional Asymmetry

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Abstract

What is the relationship between space and time in the human mind? Studies in adults show an asymmetric relationship between mental representations of these basic dimensions of experience: Representations of time depend on space more than representations of space depend on time. Here we investigated the relationship between space and time in the developing mind. Native Greek-speaking children watched movies of two animals traveling along parallel paths for different distances or durations and judged the spatial and temporal aspects of these events (e.g., Which animal went for a longer distance, or a longer time?). Results showed a reliable cross-dimensional asymmetry. For the same stimuli, spatial information influenced temporal judgments more than temporal information influenced spatial judgments. This pattern was robust to variations in the age of the participants and the type of linguistic framing used to elicit responses. This finding demonstrates a continuity between space-time representations in children and adults, and informs theories of analog magnitude representation.

Keywords: ATOM; Conceptual development; Greek; Metaphor; Space; Time

What is the relationship between space and time in the human mind? This question has long been the subject of philosophical inquiry and psychological experimentation (e.g., Cohen, 1967; Helson, 1930; Locke, 1689/1995; Mach, 1886/1897; Piaget, 1927/1969; Price-Williams, 1954). There is now no doubt that space and time are intimately linked in our minds, yet the nature of this relationship remains controversial.

Two sets of proposals have emerged, one suggesting a symmetric and the other an asymmetric relationship between space and time in the mind. The first view arises from studies of analog magnitude processing in children and animals (Church & Meck, 1984; Gallistel &

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Gellman, 2000), and from neurological data showing shared brain areas for processing space, time, and quantity (e.g., Basso et al., 1996). Observations from these disparate sources were synthesized in A Theory of Magnitude (ATOM; Walsh, 2003). According to ATOM, space, time, and number are all represented in the brain and mind by a common analog magnitude system. ATOM is appealingly simple, and it appears consistent with a large body of data from several fields.

Implicit in ATOM, however, is an assumption that time, space, and number are symmetrically interrelated. Indeed, if these dimensions are all manifestations of a common magnitude metric, there is no a priori reason to posit that one dimension should depend asymmetrically on another. Accordingly, ATOM's neural predictions are framed in symmetrical terms, positing "overlapping brain regions" for space, time, and quantity (Walsh, 2003; p. 484). Likewise, behavioral predictions suggest symmetrical relationships among these domains. Walsh proposes that "experiments in which responses are made to two or more magnitudes on successive trials should show cross-domain, within-magnitude priming [or interference]" (2003, p. 487). Although Walsh focuses on relationships among time, space, and quantity, he suggests that ATOM may apply to all "prothetic" domains; that is, domains that can be experienced as *more* or *less* in magnitude (Stevens, 1975). But are all prothetic domains created equal?

An alternative proposal also holds that space, time, and quantity are importantly related, but in a different way. According to theories of metaphorical mental representation (e.g., Lakoff & Johnson, 1999), representations of time and quantity depend asymmetrically on representations of space. Furthermore, space is of special importance for representations in many other domains, as well, including *preference* (Casasanto, 2009a), *emotional valence* (Meier & Robinson, 2004), *intimacy* (Williams & Bargh, 2008), *social dominance* (Schubert, 2005), *kinship* (Enfield, 2005), *musical pitch* (Rusconi, Kwan, Giordano, Umiltà, & Butterworth, 2006), and *similarity* (Casasanto, 2008a).

The claim that some domains are asymmetrically dependent on others is at the core of metaphor theory. Representations of abstract things that we can never see or touch (e.g., ideas, numbers, time) are hypothesized to depend asymmetrically on representations built up through perceptuomotor experience in relatively concrete domains like space, force, and motion (Talmy, 1988). The asymmetry hypothesis follows from patterns in metaphorical language. In English, it is nearly impossible to talk about domains like time without using words that can also express spatial ideas: Vacations can be *long* or *short*, meetings can be *moved forward* or *pushed back*, deadlines can lie *ahead* of us or *behind* us. Yet it is far less common to use temporal words to talk about space (Lakoff & Johnson, 1999). Although we could say that we live "a few minutes from the station," we could just as easily express this spatial idea in spatial words, saying "a few blocks from the station."

Asymmetries in language acquisition prefigure this pattern of adult language use. In general, children produce spatial terms earlier than their temporal counterparts (for a review, see H. Clark, 1973). Young children use the word *in* spatially (e.g., *in the box*) far more than they use it temporally (e.g., *in a minute*), even though temporal uses of *in* are common in adult speech (H. Clark, 1973). Children use *here* and *there* to designate points in space before they use *now* and *then* for points in time. They produce *where* questions earlier than

when questions, and sometimes misinterpret *when* as *where*. Eve Clark reports that when young children were asked questions like “*When* did the boy jump over the fence?” they sometimes gave locative answers (e.g., “right there”), consistent with the proposal that temporal terms are acquired as metaphorical extensions of spatial terms (in H. Clark, 1973).

Semantic changes throughout history also demonstrate the priority of the spatial. The word *tempus*, which gave rise to the English *time*, the French *temps*, the Italian *tempo*, etc., meant “time” in classical Latin. Yet in earlier Latin, it meant a “space marked off” and referred to divisions of the sky (Allen, 1880):

The word [tempus] referred originally to space; the meaning ‘time’ is later, and came about in this way: the quarters of the heavens are thought of as corresponding to and standing for the parts of the day and year; east is morning, south noon, and so on. (Allen, 1880, p. 140)

Thus, the word *time*, itself, has spatial roots.

Yet, even given this convergent evidence from patterns of language change, language acquisition, and language use, it would still be imprudent to conclude that space is especially important for *thinking* about time (see Boroditsky, 2000; Casasanto, 2008a, 2009a,b; E. Clark, 2003; Slobin, 1987). Is the asymmetric relationship between space and time limited to language, or might linguistic metaphors be telling us something important about how people conceptualize these domains?

Two sets of behavioral studies have critically evaluated the claim that people not only talk about time using spatial words but also think about time using spatial representations—more than the other way round. In one series of experiments (Boroditsky, 2000), spatial primes were found to influence participants’ processing of temporal sentences (e.g., March comes before May). But importantly, temporal primes did not influence subsequent spatial reasoning, consistent with the predicted cross-dimensional asymmetry.

Another set of studies tested for an asymmetric relationship between representations of space and time using low-level psychophysical tasks, with nonlinguistic stimuli and responses (Casasanto & Boroditsky, 2008). In each task, English-speaking adults viewed lines or dots on a computer screen and reproduced either their duration or their spatial displacement, using mouse clicks to indicate the beginning and end of each spatial or temporal interval. Durations and displacements were fully crossed, so there was no correlation between the temporal and spatial 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.

Results of the initial experiment showed the asymmetric dependence of time on space that was predicted by metaphor theory. The longer a line extended in space, the longer participants judged that it lasted in time. By contrast, the temporal extent of stimuli did not influence judgments of their spatial extent. Five follow-up experiments varied the attentional, mnemonic, and perceptual demands of the stimuli, in order to rule out task-related explanations for this finding. All six experiments supported the same conclusion: Distance influences representations of duration more than duration influences representations of distance.

Thus, psycholinguistic and psychophysical data from adults show the asymmetrical relationship between space and time predicted by metaphor theory, not the symmetric relationship implied by ATOM. But what about data from children? Is it possible that space-time representations start off ATOMIC and later become metaphoric? The goal of the present study was to address this question.

Piaget studied children's conceptions of time and space extensively, and observed their close relationship. He emphasized that "time and space form an inseparable whole" in the child's mind, suggesting a symmetric relationship (1927/1969, p. 1), but he also noted that "in the case of space we can ignore time...[yet] when it comes to time we cannot abstract the spatial and kinetic relationships," suggesting an asymmetry (p. 2). Results of Piaget's experiments on time, motion, and speed suggest that children may mistakenly use spatial information for time more than the other way round (Piaget, 1927/1969, 1946/1970). However, Piaget's methods did not allow for a quantitative comparison of the cross-dimensional influences of space on time and time on space. This is what we undertake here.

Children aged 4–6 and 9–10 years old performed computerized tasks, analogous to the psychophysical tasks used previously in adults (Casasanto & Boroditsky, 2008), in which they were asked to judge either the temporal or spatial dimension of a stimulus. Participants saw pairs of cartoon snails traveling along parallel paths and judged which snail had traveled farther (relative distance) or traveled for a longer time (relative duration). Control tasks tested for understanding of the questions we used, and for the ability to judge duration and distance per se, independent of cross-dimensional interference.

In principle, there were three possible outcomes. First, if spatial and temporal representations are independent in the child's mind, then no significant cross-dimensional interference should be observed. Children should be able to attend to the relevant dimension of the stimuli (whether space or time) and ignore the irrelevant dimension. In the terminology of psychophysics, this would indicate that space and time are *separable dimensions* (Garner, 1976). Based on previous results in children and adults, this outcome was not likely, nor was it predicted by either theory we were evaluating.

Alternatively, if spatial and temporal representations are symmetrically dependent on one another, then any cross-dimensional interference observed in children's judgments should be approximately symmetric: Distance should modulate duration judgments, and vice versa. This outcome would be most consistent with the central claim of ATOM and suggest that space and time are *integral dimensions*.

Finally, if mental representations of time are asymmetrically dependent on mental representations of space, then we should find an asymmetrical pattern of cross-dimensional interference: Distance should affect duration estimates more than duration affects distance estimates. This would indicate that space and time are *asymmetrically separable dimensions*, consistent with predictions of metaphor theory and with data from adults.

Testing these relationships between space and time in English-speaking children is complicated by the fact that English speakers usually use distance words to talk about duration. Asking children to compare "how long" events last in the most natural ways could induce cross-dimensional confusions by using distance-related words in both spatial and temporal contexts. Fortunately, in other languages such as Greek, it is more natural to talk about

duration without using distance words. For example, whereas English speakers use the distance-related phrase *long time* more frequently than the non-distance-related alternative *much time*, the opposite is true for the Greek translation equivalents: *μακρύ χρονικό διάστημα* [makry chroniko diastima] (tr. “large time distance”) is less frequent than *πολλή ώρα* [polli ora] (tr. “much time”). In addition to using distance words to talk about time, per se, English speakers also typically use them to describe the duration of events, such as a *long meeting*. In Greek, however, this expression would be translated most naturally using an amount word: *[συνάντηση που διήρκεσε πολύ]* [synantisi pou dierkese poli] (tr. “meeting that lasts much”; see Casasanto, 2008b; Casasanto et al., 2004).

Here we tested for distance-duration interference in native Greek-speaking children, to take advantage of the separability of distance and duration in the Greek language. This allowed us to phrase questions naturally, so that they could be understood easily by kindergarteners, without the risk of inducing superficial cross-dimensional confusions. We varied the wording of the temporal questions across participants (i.e., Distance Wording, No Distance Wording), to determine whether the phrasing of the questions influenced responses.

1. Methods

1.1. Participants

Native Greek-speaking children ($n = 99$) from schools in Thessaloniki participated after giving verbal assent, and with the informed consent of their parents and teachers. The younger group ($n = 47$) ranged in age from 4.5 to 5.9 years old ($M = 61$ months, $SD = 4$ months), and the older group ($n = 52$) from 9.1 to 10.9 years old ($M = 116$ months, $SD = 3$ months). These age groups were chosen based on the ages at which Piaget (1927/1969) reported that children begin to respond sensibly to questions about relative distances and durations of two simultaneously varying stimuli, and the age by which he reported that children had largely resolved their confusion about space and time.

1.2. Design

In the $2 \times 2 \times 2 \times 2$ design there were two within-subject factors: Target Dimension (Space, Time), and Dimensional Interference (Cross-Dimensional Interference, No Cross-Dimensional Interference). The Cross-Dimensional Interference condition required children to judge either distance or duration in the presence of competing information from the other dimension. The No Cross-Dimensional Interference condition tested distance and duration judgments in the absence of competing information from the other dimension. There were also two between-subject factors: Age (Younger, Older) and Question Wording (Distance Wording, No Distance Wording). Questions about duration contained Distance Wording for about half of the participants (e.g., Which one went for a *longer* time?), and No Distance Wording for the other half (e.g., Which one went for *more* time?)

1.3. Materials and procedure

Each participant performed three tasks: Racing Snails (the main Distance-Time interference task), Jumping Snails (a task to test children's ability to judge duration independent of spatial interference), and Static Lines (a task to test children's ability to judge distance independent of temporal interference). Each task is described below.

Stimuli were presented on a Macintosh laptop (resolution = 1024×768 pixels) and were followed by written questions (displayed for the experimenter's benefit). The first question of each trial was intended to focus children's attention on the stimulus event and to allow the experimenter to evaluate whether the child was paying attention. The second question, which asked children to judge either relative distance or relative duration, was of critical interest.

Children were tested individually at their schools, in a private room away from other children. Each child completed a total of 18 trials (12 cross-dimensional interference trials and six no-interference control trials). Testing lasted about 10–15 min.

1.3.1. Racing snails (distance-time interference task)

Two snails, one above the other, began at the left edge of the screen and "raced" rightward along parallel tracks. All stimuli remained in their final resting positions until after the child responded. One snail was blue and the other red, so that they would be visually discriminable and easy for the child to name (e.g., "the blue one"). The assignment of colors to the top and bottom snails was counterbalanced across participants.

There were three types of movies, placing the snails in different space–time relationships relative to one another. The two snails traveled: (a) Different distance, different time, (b) Different distance, same time, or (c) Same distance, different time. Distances traveled were either 400 or 600 pixels, and durations of travel were either 4 or 6 s. There were two variants of each movie type, in which either the top or the bottom snail traveled longer in space or time. This control was implemented in case participants who had an overall preference to choose the snail on the top or the bottom. This resulted in six movies that could be viewed serially without repetition.

Each participant saw all six of the Racing Snails movies twice, once in each of two blocks: a Time Question block and a Space Question block. The order of movies within each block was randomized.

Before the Space Question block, the experimenter encouraged the child to pay attention to how far the snails traveled. When the child was ready, the experimenter presented the movies one at a time, following each movie with these questions (in Greek): 1. Did the two snails stop at the same place? (*Σταμάτησαν τα δύο σαλιγκάρια στο ίδιο σημείο*) [Stamatistan ta dyo saligkaria sto idio simeio?] 2. Did one of the snails go farther? (*Πήγε κάποιο από τα σαλιγκάρια πιο μακριά;*) [Pige kapoio apo ta saligkaria pio makria?] If the child indicated "yes" without specifying which snail had gone farther, the experimenter continued: Which one of the two? (*Ποιο από τα δύο*) [Poio apo ta dyo?]

Likewise, before the Time Question block, the experimenter encouraged the child to pay attention to the time it took for the snails to travel across the screen. When the child was ready, the experimenter presented the movies one at a time, following each movie with: 1. Did the two snails stop at the same time? (*Σταμάτησαν τα δύο σαλιγκάρια την ίδια στιγμή*) [Stamatisan ta dyo saligkaria tin idia stigmi?] The phrasing of the second question depended on the version of the experiment. In the Distance Wording condition, the experimenter asked: 2. Did one of the snails move for a longer time? Which one? (*Κινήθηκε κάποιο από τα σαλιγκάρια μακρύτερο χρονικό διάστημα; Ποιο*) [Kinithike kapoio apo ta saligkaria makrytero chroniko diastima? Poio?] In the No Distance Wording condition, she asked: 2. Did one of the snails move for more time? Which one? (*Κινήθηκε κάποιο από τα σαλιγκάρια περισσότερη ώρα*) [Kinithike kapoio apo ta saligkaria perissoteri ora?] This phrasing avoided using any distance words that might create or enhance cross-dimensional interference from the (irrelevant) spatial dimension of the stimuli.

1.3.2. Static lines (distance judgment control task)

The static lines task was used to test children's ability to make distance judgments without any competing temporal information. Children judged three pairs of static lines presented one pair at a time, one above the other. One line was red and the other blue, with the colors of the top and bottom lines counterbalanced across participants. The lines were either 400 or 600 pixels in length and came in three combinations: (a) top line longer, (b) bottom line longer, or (c) both lines the same length (600 pixels). The experimenter asked: 1. Are the lines the same length? (*Είναι οι γραμμές αυτές το ίδιο μακριές*) [Einaí oi grammes aftes to idio makries?] 2. Is one of the lines longer? Which one is longer? (*Είναι κάποια από τις γραμμές αυτές μακρύτερη; Ποια γραμμή είναι μακρύτερη*) [Einaí kapoia apo tis grammes aftes makryteri? Poia grammi einai makryteri?]

1.3.3. Bouncing snails (duration judgment control task)

The bouncing snails task tested children's ability to make duration judgments without any competing distance information. Children judged three movies of the red and blue snails bouncing up and down in place, one above the other. The colors of the top and bottom snails were counterbalanced across participants. Each of the snails bounced for either 4 or 6 s, in one of three combinations: (a) top snail bounced longer, (b) bottom snail bounced longer, or (c) both snails bounced for the same duration (6 s). Although the snails traveled a small distance up and down while bouncing, there was no lateral motion and no net displacement. The experimenter asked the same questions as in the Time block of the Jumping Snails questions, using Distance Wording (i.e., longer time) in one version of the experiment and No Distance Wording (i.e., more time) in the other.

2. Results

Participants' judgments of relative distance and relative duration are summarized in Fig. 1A–D.¹ The proportion of correct responses from each of the four groups of partici-

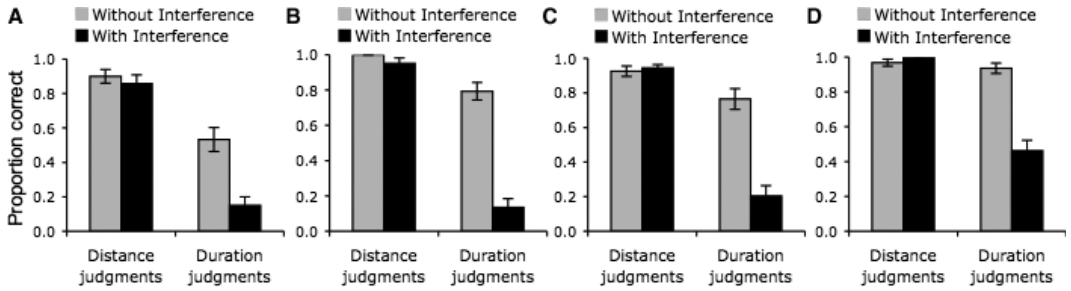


Fig. 1. Proportion of correct distance and duration responses in each group of participants. (A) Younger children, Distance wording. (B) Younger children, No Distance Wording. (C) Older children, Distance Wording. (D) Older children, No Distance Wording. Error bars indicate *SEM*.

pants (i.e., Older and Younger participants in the Distance Wording and No Distance Wording conditions) were first analyzed in four separate 2×2 ANOVAS, with Target Dimension (Space, Time) and Interference (With Interference, Without Interference) as within-subject factors. The same patterns were found in all four groups (*F* tests are reported in Table 1).

In every group there was a main effect of Interference, indicating better performance during the no-interference tasks (Jumping Snails and Static Lines) than during the cross-dimensional interference task (Racing Snails). Additionally, there was a main effect of Target Dimension, indicating better performance during Space trials compared to Time trials, overall. Crucially, there was also a highly significant interaction of Interference and Target Dimension, indicating that the effect of cross-dimensional interference was much greater for duration judgments than for distance judgments.

Table 1

Results of the 2×2 ANOVAS conducted on accuracy rates (% correct responses) in each group of children, corresponding to Fig. 1A–D

Age Group	Wording	Effect	<i>F</i> Value (<i>df</i>)	<i>p</i> Value
Younger	Distance	Target Dimension	66.63 (1,19)	.000
		Interference	12.96 (1,19)	.002
		Dimension \times Interference	8.97 (1,19)	.007
	No Distance	Target Dimension	105.73 (1,26)	.000
		Interference	31.13 (1,26)	.000
		Dimension \times Interference	45.94 (1,26)	.000
Older	Distance	Target Dimension	153.92 (1,20)	.000
		Interference	74.28 (1,20)	.000
		Dimension \times Interference	82.66 (1,20)	.000
	No Distance	Target Dimension	68.24 (1,30)	.000
		Interference	42.69 (1,30)	.000
		Dimension \times Interference	47.39 (1,30)	.000

It was possible to quantify the asymmetry in cross-dimensional interference while controlling for differences in children's ability to judge space and time, per se, by subtracting the proportion of correct responses during Interference trials from the proportion correct during No-Interference trials for the same target dimension: Effect of distance on time judgments = [(% Correct time judgments without distance interference) – (% Correct time judgments with distance interference)]; Effect of time on distance judgments = [(% Correct distance judgments without temporal interference) – (% Correct distance judgments with temporal interference)].

The magnitude of these cross-dimensional interference effects was compared across versions of the task and across age groups using a mixed ANOVA with Age (Older, Younger) and Wording (Distance Wording, No Distance Wording) as between-subject factors and Target Dimension (Space, Time) as a within-subject factor (Fig. 2). Results showed a highly significant main effect of Target Domain ($F(1,95) = 139.20, p = .00001$), but no main effects of Wording ($F < 1$) or of Age ($F < 1$). Planned comparisons showed a significant cross-dimensional asymmetry in each group, tested individually; the effect of distance on time judgments was greater than the effect of time on distance judgments (Younger Children Distance Wording: $t(19) = 3.00, p = .004$; Younger Children No Distance Wording: $t(26) = 6.79, p = .00001$; Older Children Distance Wording: $t(20) = 9.07, p = .00001$; Older Children No Distance Wording: $t(30) = 6.87, p = .00001$).

Crucially, there were no two-way interactions of Target Domain with Age, or of Target Domain with Wording ($F_s < 1$). That is, the asymmetric effect of distance on time judgments was robust to variations in the wording of the questions and the age of the participants.

There was a weak and unexpected three-way interaction of Wording, Target Domain, and Age ($F(1,95) = 4.05, p = .05$). This was driven by the older children's performance on temporal judgments in the distance wording conditions, which was much poorer with spatial interference than without (Fig. 1C). Distance Wording for duration ("longer time") is less

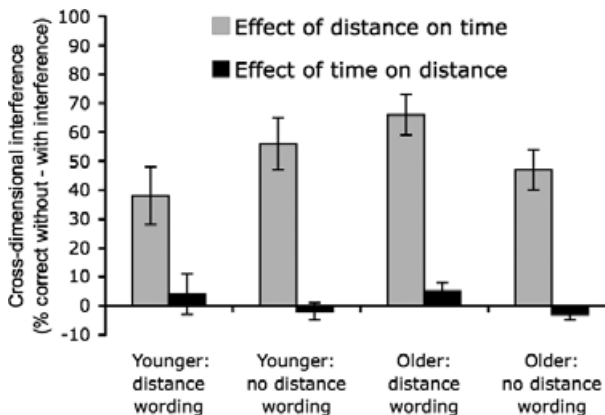


Fig. 2. Comparison of cross-dimensional interference effects across age groups and question wordings. Error bars indicate SEM.

common in Greek than the wording used in the No Distance Wording condition (“more time”; Casasanto, 2008b). But this three-way interaction does not simply indicate that participants were confused by the less standard phrasing, in general, because there was no main effect of Wording, and no two-way interactions of Wording with other factors. Rather, it is possible that for older children the less-frequent distance wording may have seemed pragmatically marked and may have oriented attention to the irrelevant spatial dimension of the stimulus during time questions, enhancing the highly significant cross-dimensional asymmetry that was found across all four groups of children.

2.1. *Is space just easier than time?*

Two additional analyses explored this cross-dimensional asymmetry in light of the participants’ better performance on distance judgments, overall. Are participants simply better at judging distance than judging duration? The fact that we found a highly significant interaction of Interference with Target Domain across all four groups argues against this interpretation. Participants were not just good at judging space and bad at judging time; rather, they were particularly bad at judging time in the presence of spatial interference (but not vice versa). Still, in principle, these interactions could arise in part as an artifact of nearly perfect performance on space trials: a ceiling effect.

To evaluate this possibility, we tested each group’s spatial performance against ceiling using one-sample *t* tests. Performance on the Static Lines task was below perfect performance for three of the four groups (Younger Children Distance Wording: $t(19) = 2.34$, $p = .03$; Younger Children No Distance Wording: $t(26) = 2.73$, $p = .01$; Older Children No Distance Wording: $t(30) = 1.79$, $p = .08$, two-tailed). Likewise, performance on the Space Question block of the Racing Snails task was below perfect performance for three of the four groups (Younger Children Distance Wording: $t(19) = 2.68$, $p = .02$; Younger Children No Distance Wording: $t(26) = 2.37$, $p = .03$; Older Children Distance Wording: $t(20) = 1.83$, $p = .08$, two-tailed). Both groups of younger children showed the predicted cross-dimensional asymmetry even though their performance was significantly below ceiling on both spatial tasks, arguing strongly against a ceiling effect. Older children’s spatial performance was closer to ceiling, but a ceiling effect is not a likely explanation of their cross-dimensional asymmetry results given that the magnitudes of the space-time asymmetry effects in the older children and the younger children were statistically indistinguishable.

To investigate this issue further, we conducted an analysis equating performance on the spatial and temporal control tasks, including only those participants who performed perfectly on control judgments of both space and time (Jumping Snails and Static Lines; $n = 50$). Performance during the Space Question blocks of the Racing Snails task was significantly better than performance during the Time Question blocks, for all groups (see Table 2 for group means and *t* tests for the difference between distance and duration judgments). Children from all four groups were combined for a further test of cross-dimensional asymmetry because the predicted pattern was found within each group individually, and because the low number of participants with perfect performance in some groups did not allow for cross-group comparisons. The effect of distance on time judgments (computed as

Table 2

Accuracy rates (% correct responses) for distance and time judgments during the cross-dimensional interference task (Racing Snails) in children who performed perfectly on the duration judgment and distance judgment control tasks (Jumping Snails, Static Lines)

Group	% Correct Space (SE)	% Correct Time (SE)	<i>t</i> Value (<i>df</i>)	<i>p</i> Value
Younger, Distance Wording (<i>n</i> = 4)	92 (8)	0 (0)	<i>t</i> (3) = 11.00	.001
Younger, No Distance Wording (<i>n</i> = 12)	94 (2)	18 (9)	<i>t</i> (11) = 8.82	.000
Older, Distance Wording (<i>n</i> = 11)	97 (4)	14 (7)	<i>t</i> (10) = 10.86	.000
Older, No Distance Wording (<i>n</i> = 23)	100 (0)	49 (7)	<i>t</i> (22) = 6.95	.000

Note. *t* Tests indicate the significance of the difference in accuracy between distance and duration judgments

described above) was significantly greater than the effect of time on distance judgments ($t(49) = 14.00$, $p = .0001$; Fig. 3). Even when children were matched on their ability to judge relative distance and relative duration, per se, their judgments under cross-dimensional interference conditions revealed the predicted space-time asymmetry.

3. Discussion

This study tested relationships between space and time in the minds of kindergarten and elementary school-aged children. Overall, children were much better at judging distance in the presence of temporal interference than judging duration in the presence of spatial interference—even when the wording of the questions, the age of the participants, and the participants' ability to judge distance and duration, per se, were taken into account. Children could ignore irrelevant temporal information in the stimuli when making judgments about space, but they had much greater difficulty ignoring irrelevant spatial information in the

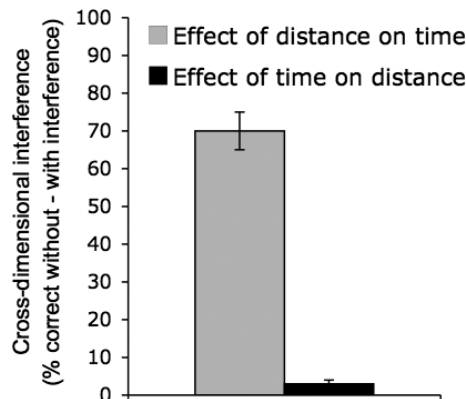


Fig. 3. Comparison of cross-dimensional interference effects in children who performed perfectly on the duration judgment and distance judgment control tasks ($n = 50$). Error bars indicate SEM.

stimulus when making judgments about time. This result reveals the same cross-dimensional asymmetry found previously in adults (Boroditsky, 2000; Casasanto & Boroditsky, 2008). It appears that space and time are *asymmetrically separable dimensions* (Garner, 1976) in children's minds.

The finding that the older children were equally susceptible to space-time interference as the younger children may seem surprising, given Piaget's reports. For Piaget, the crucial development that allowed children to reason about time in adult-like ways was the *reversibility* of operations. In physical time, events flow in one direction. But in psychological time, events must often be reversed and reordered so that the relative distance and duration of two moving objects can be appreciated independent of their relative speed (Piaget, 1927/1969). Piaget concluded that reversibility was achieved during the *concrete operational* period (age 7–11 years), by the end of which children were equipped to find logical solutions to concrete problems such as those posed by the Racing Snails task.

Although our oldest children were nearly 11 years old, at the upper bound of the concrete operational period, they showed substantial space-time interference, which Piaget suggested should have been largely resolved. Our conclusions differ from Piaget's, in part, because we tested for age-related changes in the space-time asymmetry in particular, as opposed to age-related increases in the ability to make temporal judgments, in general. Indeed, the older children performed somewhat better on time judgments than the younger children, overall (see Fig. 1). But the magnitude of the cross-dimensional interference effect of distance on time (which we computed to control for the children's overall ability to judge duration) did not change across age groups (see Fig. 2).

The persistence of space-time interference in the older group suggests that although concrete operations may be necessary to make relative duration judgments, they are not sufficient to overcome space-time interference. This point is illustrated by previous studies in adults (Casasanto & Boroditsky, 2008). In tasks analogous to the Racing Snails that required finer-grained duration judgments, college students at MIT (who had presumably mastered concrete operations) showed a pattern of space-time interference similar to the pattern found in the present study.

Of course, it is always possible that the peculiarities of any one task could artificially create a space-time asymmetry. Importantly, space-time asymmetries have been found previously across a variety of tasks, in children and adults. Tversky, Kugelmass, and Winter (1991) did not intend to test for a space-time performance asymmetry, but they demonstrated one, nevertheless. They asked children to produce a diagram of three objects in a spatial series and three events in a temporal series. Across cultures, children produced adult-like diagrams far more often for spatial than for temporal series, even though the space and time tasks required nearly identical responses (see Experiment 2). In adults, Boroditsky (2000) found asymmetric priming from spatial to temporal sequences both in offline questionnaires and in an online reaction time task.

Of most direct relevance to the current study, Casasanto and Boroditsky (2008) demonstrated asymmetric distance-duration interference in a psychophysical task (described in the introduction). We conducted several experiments in an attempt to establish the limits of the effect, and to rule out possible task-related causes. For example, is it possible that space

influenced time asymmetrically because the spatial dimension of the stimulus was more salient? To find out, in one version of the task the temporal dimension of the stimulus was made extra salient by pairing it with a tone, so that temporal information was available in both auditory and visual modalities, whereas spatial information was only available visually. But the magnitude of the space-time asymmetry was unchanged (see Experiment 4). Maybe space affected time asymmetrically because it was more memorable? Another version of the task was designed to equate memory demands across dimensions, but asymmetry results were unaffected (see Experiment 5). Could the apparent influence of distance on duration really be an effect of speed? In another version of the task, static stimuli produced nearly the same cross-dimensional asymmetry as moving stimuli (see Experiment 6). This indicates that distance was influencing time representations asymmetrically independent of motion or speed. In short, the distance-duration asymmetry that we found in adults stubbornly resisted our repeated attempts to make it go away.

One other aspect of the tasks we used here merits consideration. Importantly, on trials testing for cross-dimensional interference, children received exactly the same spatial and temporal information before answering either the spatial or the temporal questions (i.e., they saw the identical Racing Snails movies). This task was a digital adaptation of a task Piaget conducted using mechanical snails racing across a physical surface. We made an effort to preserve important regularities of the physical world in our digital facsimile. Because the snails remained on the screen in their final “resting” positions at the end of the race (as wind-up snails would if they were racing across a real tabletop), children had a persistent, visible spatial cue to refer to when judging the relative distance of the snails, but no persistent, visible temporal cue when judging their relative duration. This fact about the stimuli reflects a simple fact of the physical world: Unlike spatial relationships which can often be inspected and reinspected, temporal relationships are by their nature neither persistent nor visible.

Could this feature of the stimuli be responsible for the cross-dimensional asymmetry we observe? Although we cannot definitively rule out this possibility, which merits further investigation, there are strong reasons to believe that we would have obtained similar results if, for example, the snails had disappeared immediately after the race. First, the results of the Jumping Snails control task show that participants were not basing their judgments of relative duration solely on the final resting positions of the snails. For all Jumping Snails trials, both snails ended up in the same final position (relative to their starting positions and to one another). If children were judging time based only on the snails’ final positions, we would expect to see a marked difference across trial types. That is, if seeing the snails in the same final position during the question period led children to say “same” in response to the duration question, this would result in correct responses during trials for which the snails bounced for the same duration, and incorrect responses during trials for which the snails bounced for different durations. However, an analysis including all 99 participants shows no difference in accuracy during same-duration trials (mean percent correct = 77.3%, $\pm 0.04\%$) and different-duration trials (mean percent correct = 78.8%, $\pm 0.04\%$; difference of means = 1.5%, $t(98) = 0.29$, $p = .77$). Rather than judging relative duration based on the final, resting positions of the snails,

participants appear to have formed their judgments based on dynamic aspects of the stimuli, which were probably more salient.

Data from adults provide a second reason to expect that we would obtain similar results in a variant of the Snails task in which stimuli disappeared before the participant responded. This was the case in Casasanto and Boroditsky's (2008) psychophysical tasks. There was no spatial cue for participants to consult when making time judgments, yet distance still strongly influenced time estimates. While we did not run all of the same experimental variations in children that we ran in adults (due to practical limitations), it seems unlikely that young children would be immune to cross-dimensional interference from space to time under task conditions where MIT students were susceptible to it.

3.1. ATOMIC versus metaphoric representations of time

These results run contrary to the relationship between space and time suggested by Walsh's (2003) ATOM proposal. If space and time are two aspects of the same generalized mechanism for representing and comparing analog magnitudes, then why should one domain depend asymmetrically on the other, both in language and thought, adults and children? It may be possible to modify ATOM to accommodate the present data, but such modifications would need to be not only explanatorily adequate but also theoretically motivated; otherwise a metaphorical account of these space-time asymmetries should be preferred.

ATOM and metaphor theory make contrasting predictions about the relationship between space and number as well. If we take patterns in language as a source of hypotheses about conceptual structure, there should be a spatial basis for numbers, as speakers often describe them spatially as large or small, high or low. Indeed, there is abundant evidence that spatial schemas are used in the domain of number (e.g., Dehaene, Bossini, & Giraux, 1993; Lakoff & Núñez, 2000). But are mappings from space to number symmetrical or asymmetrical? In investigating such cross-dimensional relationships, it is important to distinguish the notion of *unidirectionality* from *asymmetry* (for a discussion, see Casasanto & Boroditsky, 2008). Evidence that numbers can influence space under some circumstances (i.e., that there is some degree of bidirectionality in space-number mappings) would not necessarily invalidate the hypothesized space-number asymmetry. Asymmetry does not imply unidirectionality. That is, the asymmetry hypothesis does not preclude the possibility that processing a metaphorical *target domain* such as number or time could influence processing of a metaphorical *source domain* such as space. Rather, it suggests that when appropriately compared, the influence of source on target should be greater than the influence of target on source. If the relationship between two domains is asymmetrical, whether unidirectional or bidirectional, then given symmetrical tasks (e.g., judging different dimensions of the same stimulus with appropriate controls), participants should nevertheless produce asymmetrical judgments, as in the present study.

ATOM's elegance lies in its potential to explain (at least partly) how people represent three fundamental dimensions of experience using a single mechanism. Yet the theory that abstract ideas are represented via physical metaphors has the potential to partly explain not only the handful of prothetic dimensions that psychophysicists ordinarily study but also

representations of countless other dimensions of experience, including intelligence, pride, wealth, honesty, attractiveness: anything that can be described in language (and by hypothesis conceptualized) as higher or lower, longer or shorter, bigger or smaller.

3.2. *The role of language in the space-time asymmetry*

Does using the same words to compare space and time during the experiment (e.g., *longer* distance, *longer* time) cause children to confuse these dimensions? The finding that distance influenced time judgments asymmetrically across variations in the wording of the questions rules out the possibility that children's cross-dimensional confusion was due to uncertainty about the meanings of "distance" words when they were used in temporal contexts. This finding supports Piaget's (1927/1969) claim that "linguistic similarity may increase [cross-dimensional] confusion, but it does not create it" (p. 43).

The present data leave open the question of whether spatio-temporal language has long-term effects on children's time representations. Language habits can influence space-time mappings in adults (Boroditsky, 2001; Casasanto, 2008b; Núñez & Sweetser, 2006). Does using linguistic metaphors help to create space-time mappings in the child's mind, in the first place? Or alternatively, might language influence relationships between space and time that arose over evolutionary time, or that children construct during prelinguistic developmental time, based on their physical experiences? Mental metaphors from space to time could be established as children implicitly track cross-dimensional correlations that are useful for reasoning about and acting on their physical environment (e.g., learning that as moving objects travel farther, more time passes). These prelinguistic mental metaphors could then be modified as children learn and use the metaphors in their native language, via ordinary associative learning mechanisms. Cross-linguistic comparisons are needed to clarify how linguistic experience and physical experience interact during the development of spatio-temporal concepts, and to determine whether the basic space-time asymmetry we report here transcends language-related variations in the mental representation of time that have been discovered previously (e.g., Boroditsky, 2001; Casasanto, 2008b; Núñez & Sweetser, 2006).

3.3. *Why do people use space to think about time?*

Why are space and time related asymmetrically, in language and thought? Piaget (1927/1969) proposed that space and time start out fused in the child's mind, a single metric that becomes gradually differentiated (thus, Piaget's proposal is compatible with ATOM). A priori, there may be no reason to believe that this process of differentiation should result in a representational asymmetry. Likewise, if space-time mappings are established initially as children track correlations in their physical experiences with moving objects, it would be natural to assume that symmetrical representations should develop, because correlation is a symmetrical relationship. How does asymmetry emerge between dimensions that are initially fused or symmetrically correlated?

Representations of space and time may be equally basic developmentally, and information about these dimensions may be equally present in the physical world. Yet our

capacity to observe and reconstruct these dimensions appears lopsided. As discussed above, spatial relationships are often more enduring than temporal relationships. Some aspects of time are said to be more “abstract” than their spatial analogs because we can perceive the spatial, but we can only imagine the temporal (Ornstein, 1969; cf., Evans, 2004). We can experience a spatial event like *moving the truck forward* via multiple senses: We might see it move, hear its position change, and feel the rumble of the engine as it passes. But we have no direct sensory evidence for an analogous temporal event like *moving the meeting forward*. Meetings are not the kind of entity whose motion we can see, hear, or feel (except when we physically move them in an external spatial representation of our own creation, like in a calendar).

Although space and time are symmetrically correlated in the world, we may rely asymmetrically on the dimension that is easier to perceive, remember, or reconstruct from physical evidence. We use space heuristically as an index of time because, in many cases, the spatial dimension of an event is more durable and more perceptually available than the temporal. Like other heuristics, this often works because it is based on regularities in our environment (i.e., the distance an object travels is usually a good indicator of the amount of time it takes).

The proposal that temporal representations depend in part on spatial representations allows for the possibility that 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 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 it may also import the inferential structure of spatial relations into the domain of time, facilitating the comparison of temporal intervals, transitive inference, serial ordering, and other such mental operations (Boroditsky, 2000; Casasanto, 2008b; Gentner, 2001; Pinker, 1997).

3.4. Are space-time metaphors uniquely human?

Whereas the present findings demonstrate a continuity between space-time mappings in adults and children, they underscore a difference between humans and monkeys. The psychophysical space-time tasks described above (Casasanto & Boroditsky, 2008) were adapted for use with macaques, who were trained to categorize lines presented on a computer screen as either long or short in time or space. Human adults who were run as a manipulation check showed the usual space-time asymmetry. Monkeys, by contrast, showed a significantly more symmetrical pattern of interference between space and time (Merritt, Casasanto, & Brannon, 2009). This finding raises the possibility that mental metaphors are uniquely human, and it could suggest a critical role for language. Of course, monkeys and humans also differ in countless other ways and further experiments are needed to determine what properties of our languages, cultures, or bodies give rise to the metaphoric structuring of our minds.

4. Conclusions

Space and time are related asymmetrically in children's minds. Kindergarten and elementary school-aged children can ignore irrelevant temporal information when making judgments about space, but they have difficulty ignoring spatial information when making judgments about time. This asymmetric relationship, which was predicted based on patterns in metaphorical language, does not depend on using words with confusable spatial and temporal meanings (e.g., 'long') to elicit children's responses.

This finding is consistent with the way adults appear to mentally represent space and time (Boroditsky, 2000; Casasanto & Boroditsky, 2008). It is inconsistent, however, with the most straightforward predictions of ATOM theory (Walsh, 2003), which accords equal status to representations of space, time, and other prosthetic dimensions. Using Garner-like interference tasks (Garner, 1976) as in the present study can help to clarify not only *whether* these dimensions are importantly related but also *how* they are related (i.e., symmetrically or asymmetrically), informing theories of mental magnitude representation.

Note

1. All judgments of relative duration and relative distance were included in the main analyses. We found a similar pattern of results when we analyzed duration and distance judgments only for those trials in which the children had answered the orienting question correctly, reporting whether the snails had stopped at the same time or the same place. This suggests that the space-time asymmetry we report was not due to children's inattention to the stimuli during the Racing Snails task.

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