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 (N=99) 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 time, or a longer distance?) 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 language 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: Space; Time; Metaphor; Conceptual Development; Greek; Snails

Introduction

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., Locke, 1689/1995; Cohen, 1967; Helson, 1930; Mach, 1886/1897; Piaget, 1927/1969; Price-Williams, 1954). There is now no doubt that space and time are intimately related in our minds, yet the nature of their 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 & 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 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, pg. 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, pg. 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, 2009), intimacy (Williams & Bargh, 2008), social dominance (Schubert, 2005), 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 (see H. Clark, 1973, for review). 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).

Yet, even given this convergent evidence from patterns of language acquisition and language use, it would still be imprudent to conclude that space is especially important for thinking about time (see Casasanto, 2008a, 2009). 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 around. 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 non-linguistic 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, pg. 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 (pg. 2). Results of Piaget's experiments on time, motion, and speed suggest that children may mistake space for time more than the other way around (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, 1974). 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 integral 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 (tr. 'large time distance') is less frequent than πολλή ώρα (tr. 'much time') (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.

Methods

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;5-5;9 y.o. (mean=61 mos, SD=4 mos), and the older group (n=52) from 9;1-10;9 y.o. (mean=116 mos, SD=3 mos). 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.

Design

In the 2x2x2x2 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?)

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=1024x768 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 6 no-interference control trials). Testing lasted about 10-15 minutes.

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. 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 seconds. 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 had an overall preference to choose the snail on the top or the bottom. This resulted in 6 movies that could be viewed serially without repetition.

Each participant saw all 6 of the Racing Snails movies twice, once in each of two blocks: a Space Question block and a Time Question block. The order of these blocks was counterbalanced across participants, and 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;) 2. Did one of the snails go farther? (Πήγε κάποιο από τα σαλιγκάρια πιο μακριά;) If the child indicated 'yes' without specifying which snail had gone farther, the experimenter continued: Which one of the two? (Ποιο από τα δύο;)

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;) In the Time Question block, only, 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 go for a longer time? Which one? (Κινήθηκε κάποιο από τα σαλιγκάρια μακρύτερο χρονικό διάστημα; Ποιο;) In the No Distance Wording condition, she asked: 2. Did one of the snails go for more time? Which one? (Κινήθηκε κάποιο από τα σαλιγκάρια περισσότερη ώρα;) This phrasing avoided using any distance words that might create or enhance cross-dimensional interference from the (irrelevant) spatial dimension of the stimuli.

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;) 2. Is one of the lines longer? Which one is longer? (Είναι κάποια από τις γραμμές αυτές μακρύτερη; Ποια γραμμή είναι μακρύτερη;)

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 seconds, 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 seconds). 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.

Results

Participants' judgments of relative distance and relative duration are summarized in Fig. 1a-d. The proportion of correct responses from each of the four groups of participants (i.e., Older and Younger participants in the Distance Wording and Alternative Wording conditions) were first analyzed separately, in four separate 2 X 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 reported in Table 1).

To summarize the results, in every group there was a main effect of Interference, indicating better performance during the no-interference trials (Jumping Snails and Static Lines) than during cross-dimensional interference trials (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 difference between participants' distance and duration judgments was much greater under cross-dimensional interference conditions than under no-interference conditions. To paraphrase, children were not simply good at judging space and bad at judging time; they were worse at judging time in the presence of irrelevant spatial information. By contrast, irrelevant temporal information had little effect on spatial judgments.

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, Alternative 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 ($F(1,95=139.20$, $p<.0001$), and no main effects of Wording ($F<1$) or of Age ($F<1$). There was a weak and unexpected three-way interaction of Wording, Target Domain, and Age ($F(1,95)=4.05$, $p<.05$), but no interaction of Target Domain with Age, or of Target Domain with Wording (F's<1).

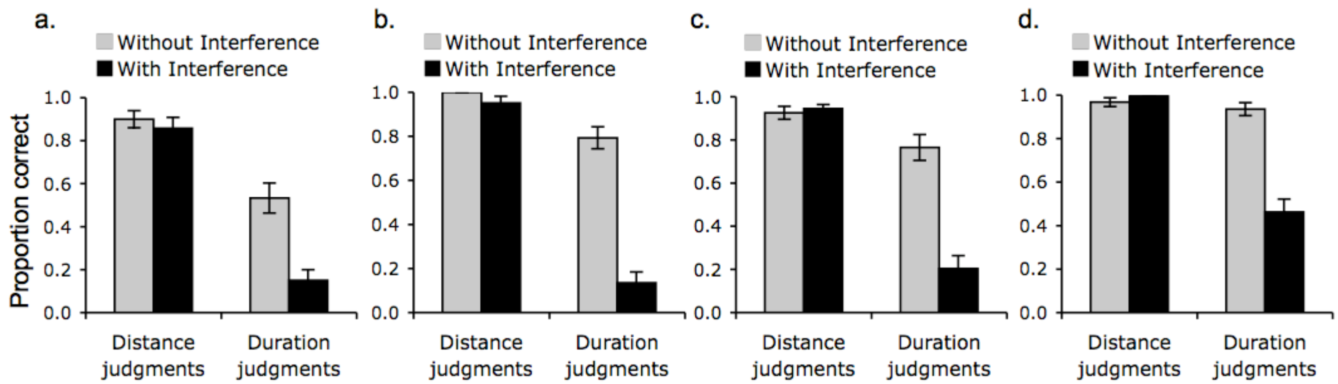

Figure 1. Proportion of correct distance and duration responses in each group of participants. (a) Younger children, Distance wording. (b) Younger children, Alternative wording. (c) Older children, Distance Wording. (d) Older children, Alternative wording. Error bars indicate s.e.m.

Age group	Wording	Effect	F-value (df)	p-value
Younger	Distance	Target Dimension	66.63(1,19)	0.000
		Interference	12.96(1,19)	0.002
		Dimension * Interference	8.97(1,19)	0.007
	Alternative	Target Dimension	105.73(1,26)	0.000
		Interference	31.13(1,26)	0.000
		Dimension * Interference	45.94(1,26)	0.000
Older	Distance	Target Dimension	153.92(1,20)	0.000
		Interference	74.28(1,20)	0.000
		Dimension * Interference	82.66(1,20)	0.000
	Alternative	Target Dimension	68.24(1,30)	0.000
		Interference	42.69(1,30)	0.000
		Dimension * Interference	47.39(1,30)	0.000

Table 1. Results of the 2 x 2 ANOVAs conducted on accuracy rates (% correct responses) in each group, corresponding to panels 1a-d, above.

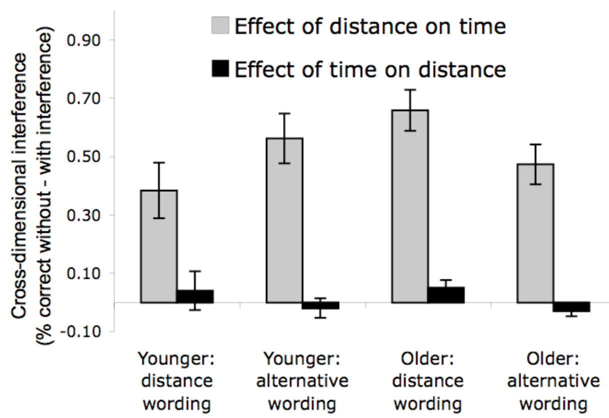

Figure 2. Comparison of cross-dimensional interference effects across age groups and question wordings.

General 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 they were at 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. This finding constitutes the cross-dimensional asymmetry predicted by metaphor theory, and reveals that space and time are asymmetrically integral dimensions (Garner, 1974) in the minds of children, as in the minds of adults.

These results run contrary to the simplest predictions derived from Walsh's (2003) ATOM proposal. If space and time are two aspects of, or products of, a 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 the observed space-time asymmetries should be preferred.

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 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*, *more* or *less*.

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, since speakers often describe them as *large* or *small*, *high* or *low*. Indeed, there is abundant evidence that spatial schemas are mapped onto the domain of number (e.g., Dehaene, Giraux, & Bosini, 1993; Lakoff & Núñez, 2000). But is there evidence for a symmetrical mapping from numbers to space? In investigating such cross-dimensional relationships, it is important to distinguish the notion of *directionality* from *asymmetry* (see Casasanto & Boroditsky, 2008 for discussion). Evidence that numbers *can* influence space under some circumstances (i.e., that there is some degree of bidirectionality) would not necessarily invalidate the hypothesized space-number asymmetry. Whether or not there are bidirectional influences between domains, the metaphor theorist posits that when given *symmetrical tasks* (e.g., judging different dimensions of the same stimulus), participants should nevertheless produce *asymmetrical judgments*.

Although 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 in the introduction (Casasanto & Boroditsky, 2008) were adapted for use with Macaques, who were trained to judge lines presented on a computer screen as either long or short in time or space. By contrast with the human 'control subjects' who showed the usual space-time asymmetry, monkeys showed more symmetrical interference from the spatial to the temporal dimension of stimuli, and vice versa (Merritt, Casasanto, & Brannon, 2009). Further experiments are needed to determine whether 'mental metaphors' from space to time are uniquely human, and if so, what properties of our languages or bodies might give rise to the metaphoric structuring of our minds.

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