Benjamin Pitt
@BenPitt

Follow

Just published a new @ScienceAdvances paper with @FerrignoStephen, @CantlonLab, @D_Casasanto, @LanguageMIT, and @spiantado. It's about the origins of the mental number line and other spatial mappings that shape our most basic concepts. Here's what we found...

SCIENCE ADVANCES | RESEARCH ARTICLE

NEUROSCIENCE

Spatial concepts of number, size, and time in an indigenous culture

Benjamin Pitt[1]*, Stephen Ferrigno[2], Jessica F. Cantlon[3], Daniel Casasanto[4], Edward Gibson[5], Steven T. Piantadosi[1]

In industrialized groups, adults implicitly map numbers, time, and size onto space according to cultural practices like reading and counting (e.g., from left to right). Here, we tested the mental mappings of the Tsimane', an indigenous population with few such cultural practices. Tsimane' adults spatially arranged number, size, and time stimuli according to their relative magnitudes but showed no directional bias for any domain on any spatial axis; different mappings went in different directions, even in the same participant. These findings challenge claims that people have an innate left-to-right mapping of numbers and that these mappings arise from a domain-general magnitude system. Rather, the direction-specific mappings found in industrialized cultures may originate from direction-agnostic mappings that reflect the correlational structure of the natural world.

INTRODUCTION

In many cultures, people reason about number, time, and other conceptual domains using space. For example, Americans and Europeans implicitly associate smaller numbers with the left side of space and larger numbers with the right side, forming an implicit "mental number line" (*1*, *2*). Although the mental number line has been the subject of hundreds of studies (*3*), its phylogenic origins remain controversial. Some scholars have proposed that a left-to-right mapping of number may be innate, based on studies of human infants and nonhuman animals like monkeys, chicks, and fish (*4*–*8*). For example, after habituating to visual arrays with a fixed number of dots, human neonates looked to the left in response to smaller numbers of dots and to the right in response to larger numbers (*9*). Innate left-to-right mappings may not be unique to number (*10*); on some accounts, number shares representational structure with other conceptual domains, including time and size, as part of a "generalized magnitude system" in parietal cortex (*11*–*14*). On the strongest versions of this theory, the mental number line is a manifestation of a domain-general "mental magnitude line" that provides common spatial structure to mappings of number, size, and time, among others (*15*, *16*). If so, then any spatial biases in number mappings should also be found for mappings of these other domains.

These proposals are difficult to test in industrialized groups, where any innate spatial biases may be masked by cultural conventions that cause number, time, and other domains to be spatialized in a consistent direction (e.g., reading and counting from left to right). These conventions are enough to influence mental mappings of these domains, which vary in direction with spatial practices like reading (*17*–*19*) and which can be independently changed by brief spatial training (*20*, *21*). These effects support theories of metaphorical mental representation positing that each mental mapping arises from the correlations between the relevant domains (e.g., space and number; space and time) that are found in the natural and cultural environment (*21*–*23*). On this alternative account, direction-specific cultural experiences act on mental mappings that initially lack specific direction (*20*).

To isolate effects of cultural experience, we tested mental mappings in the Tsimane', an indigenous group of farmer-foragers who live in the Amazon basin of Bolivia (*24*). With little or no formal education, low levels of literacy and numeracy, and few modern technologies (*25*), many Tsimane' adults have scant experience with the directional practices that may mask innate spatial biases in industrialized cultures. The Tsimane' therefore allowed us to study the origins of mental mappings, in two ways. First, if mental mappings of number (or other domains) have rightward direction by default, then unindustrialized groups like the Tsimane' should show this spatial bias (*26*–*29*). Second, if mental mappings inherit "a common pattern of spatial organization" (*15*) from a mental magnitude line, then a given person should map different domains (e.g., number, time, size) in the same direction (e.g., all right-to-left), even if that direction differs across individuals (*11*, *16*).

RESULTS

Experiment 1: Number and size mappings on the lateral axis

In experiment 1, we tested number and size mappings in Tsimane' adults ($N = 96$; ages 17 to 78) by having them manually arrange stimuli that varied in number (1 to 5 dots) or size (1 to 5 inches) along a lateral response array, as shown in Fig. 1 (left). We included comparison groups of U.S. adults ($N = 18$; ages 29 to 50), who have extensive experience with left-to-right cultural practices, and of U.S. children ($N = 31$; ages 3:1 to 5:5), who have relatively little such experience. If people have an innate predisposition to map numbers or other magnitudes from left to right, then those spatial biases should be evident in all three groups.

Figure 2 shows the distribution of mapping scores that each group (columns) produced for each domain (rows), contrasted with the chance distribution (in gray). U.S. adults showed a strong rightward bias in their mappings; both number and size increased monotonically from left to right in every case. By contrast, Tsimane' adults and U.S. children showed no such bias for number or size (whether these domains were analyzed separately or pooled together). Rather, participants were equally likely to map the stimuli to the left

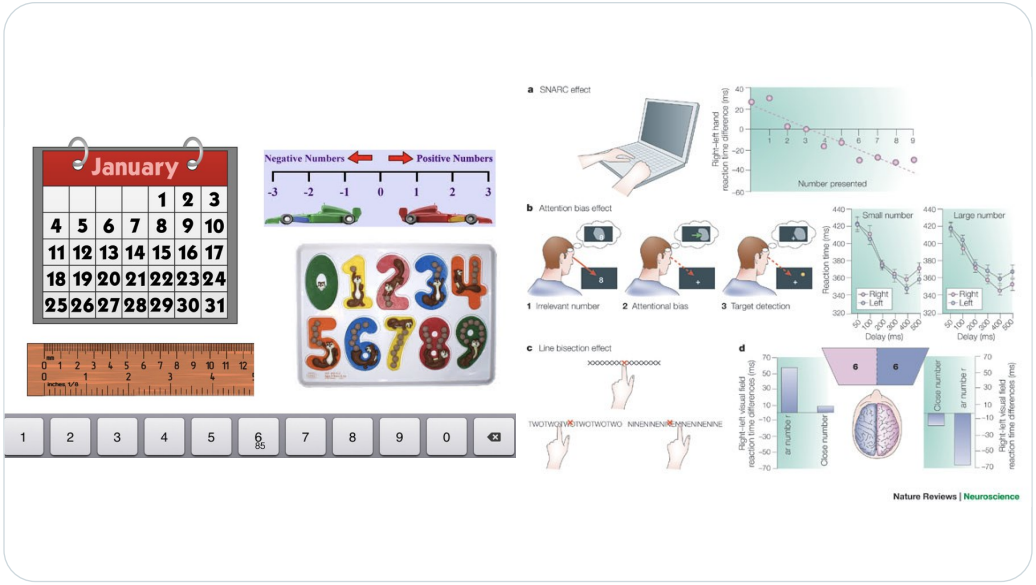
[1]Department of Psychology, UC Berkeley, Berkeley, CA, USA. [2]Department of Psychology, Harvard University, Cambridge, MA, USA. [3]Department of Psychology, Carnegie Mellon University, Pittsburgh, PA, USA. [4]Department of Human Development, Cornell University, Ithaca, NY, USA. [5]Department of Brain and Cognitive Sciences, MIT, Cambridge, MA, USA.
*Corresponding author. Email: pittsburgh@uchicago.edu

10:01 AM · Aug 13, 2021

2 34 121 16

Benjamin Pitt @BenPitt · Aug 13, 2021

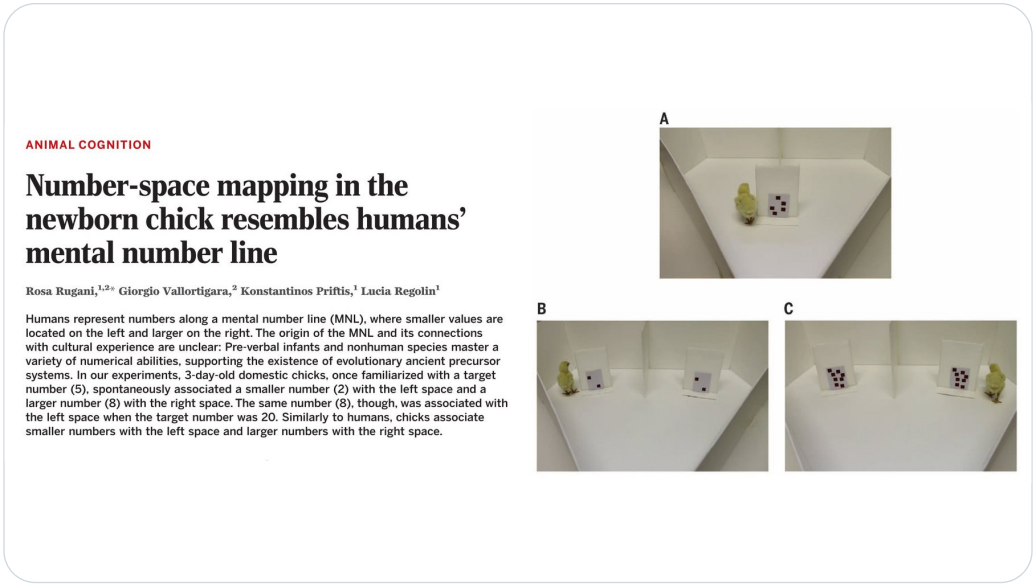
In WEIRD cultures like ours, adults implicitly map numbers, time, and size onto space according to cultural practices like reading and counting. For example, in the mental number line, Americans associate smaller numbers with the left and larger numbers with the right.



1 6 6

Benjamin Pitt @BenPitt · Aug 13, 2021

Some people suggest that this left-right directional bias could actually be innate, since human newborns, monkeys, and even baby chicks seem to show it. @gVallortigara @LuciaRegolin



ANIMAL COGNITION

Number-space mapping in the newborn chick resembles humans' mental number line

Rosa Rugani,[1,2]* Giorgio Vallortigara,[2] Konstantinos Priftis,[1] Lucia Regolin[1]

Humans represent numbers along a mental number line (MNL), where smaller values are located on the left and larger on the right. The origin of the MNL and its connections with cultural experience are unclear: Pre-verbal infants and nonhuman species master a variety of numerical abilities, supporting the existence of evolutionary ancient precursor systems. In our experiments, 3-day-old domestic chicks, once familiarized with a target number (5), spontaneously associated a smaller number (2) with the left space and a larger number (8) with the right space. The same number (8), though, was associated with the left space when the target number was 20. Similarly to humans, chicks associate smaller numbers with the left space and larger numbers with the right space.

2 5

Benjamin Pitt @BenPitt · Aug 13, 2021

We tested these mappings in the Tsimane', a group of indigenous South Americans. As farmer-foragers, many Tsimane' adults have little experience with reading, math, and other directional practices that could mask any innate directional bias. @koleenmccrink

1 5

Benjamin Pitt @BenPitt · Aug 13, 2021

In our task, participants arranged cards along a linear strip of Velcro. They spatialized three conceptual domains (size, time, and number) on all three spatial axes (lateral, vertical, and sagittal), in whatever way made sense to them. Here's a vertical mapping of time:

2 7

Benjamin Pitt @BenPitt · Aug 13, 2021

Participants arranged stimuli systematically (i.e. in order) but they showed no directional preference for any domain on any axis. Magnitude was just as likely to increase leftward as rightward, upward as downward, and forward as backward: Systematicity w/o bias.

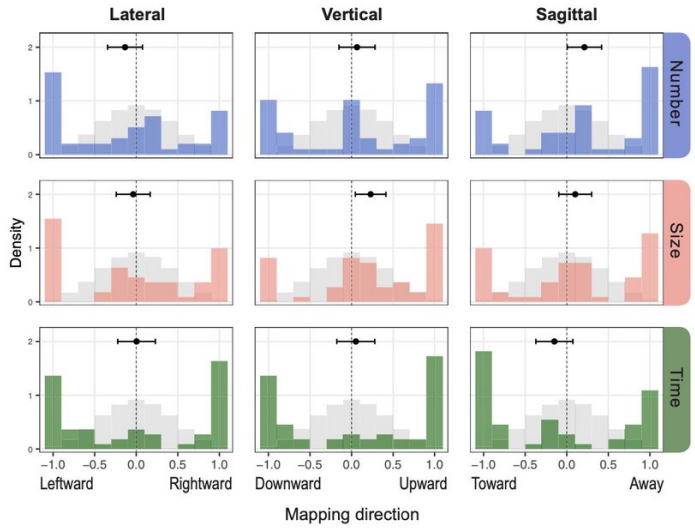


Fig. 3. Number, size, and time mappings on three spatial axes. Mappings ranged from perfectly negative (i.e., leftward, downward, or toward) to perfectly positive (i.e., rightward, upward, or away), with less orderly mappings in the middle. Colored bars show participants' mappings of number (blue), size (pink), and time (green), which differed significantly from chance (gray). Black dots and whiskers show mean mapping scores and uncorrected 95% confidence intervals.

1 1 9

Benjamin Pitt @BenPitt · Aug 13, 2021

This pattern is hard to explain on accounts where left-to-right number lines are innate.

the right as to the left. This pattern, which we found in three independent samples, is consistent with previous findings in unindustrialized adults (*26*, *29*) but contrasts with studies of infants and nonhuman animals, who appear to show a rightward bias. These different effects are likely due to substantial differences in methodology (i.e., studies of infants and animals cannot instruct their participants to respond on the basis of number) and therefore may reflect different cognitive processes. For example, some scholars have suggested that the effects in infants and nonhuman animals may reflect hemispheric specialization for spatial frequency (*42*) or emotional motivation (*8*) rather than spatial-numerical associations.

1 1 8

Benjamin Pitt @BenPitt · Aug 13, 2021

We found similar results in US kids, who were as happy to have number and size increase to the left as to the right. Only US adults showed a clear directional bias: 100% made left-to-right mappings. (Also see cool work in the Yupno by @TylerMarghetis, @kensycoop, & Rafael Núñez)

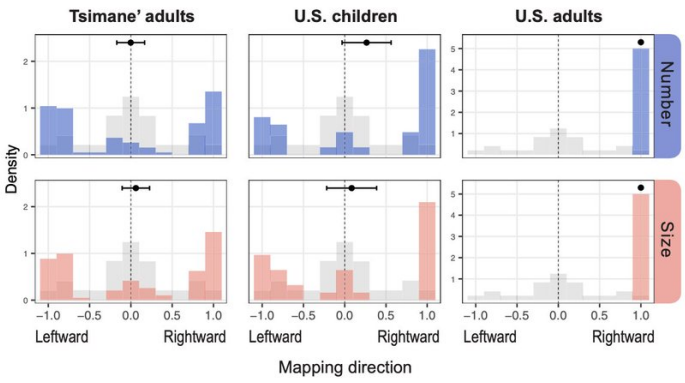


Fig. 2. Lateral number and size mappings in three populations. Mappings ranged from perfectly leftward to perfectly rightward, with less orderly mappings in the middle. Colored bars show participants' mappings of number (blue) and size (pink), which differed significantly from chance (gray). Black dots and whiskers show mean mapping scores and uncorrected 95% confidence intervals.

1 1 9

Benjamin Pitt @BenPitt · Aug 13, 2021

We also wanted to see how consistent individual participants were in mapping direction. Some theories (@LourencoLab) say people have a shared "mental magnitude line," in which number, size, and time should all go in the same direction, at least in the same mind. They did not.

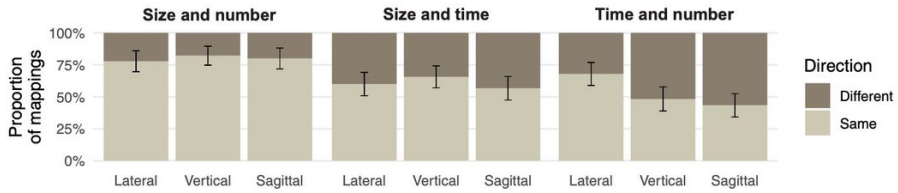
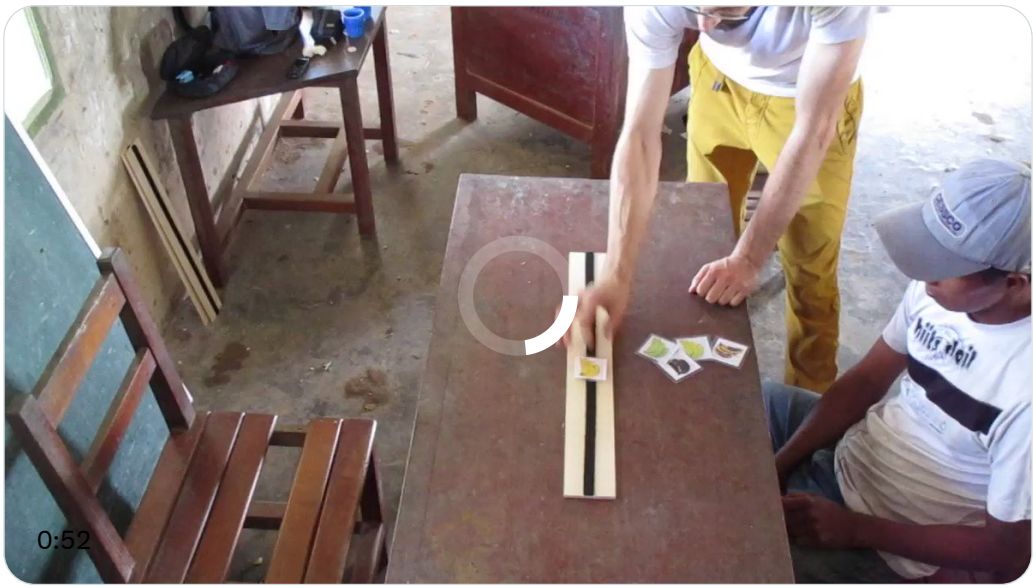


Fig. 4. Within-participant consistency of mapping direction for each pair of domains. Error bars show the SEM.

1 7

Benjamin Pitt @BenPitt · Aug 13, 2021

Rather, participants often mapped different domains in opposite directions. For example, this Tsimane' participant maps time perfectly from left to right and then, in the very next trial, maps numbers in the opposite direction.



1 2 10

Benjamin Pitt @BenPitt · Aug 13, 2021

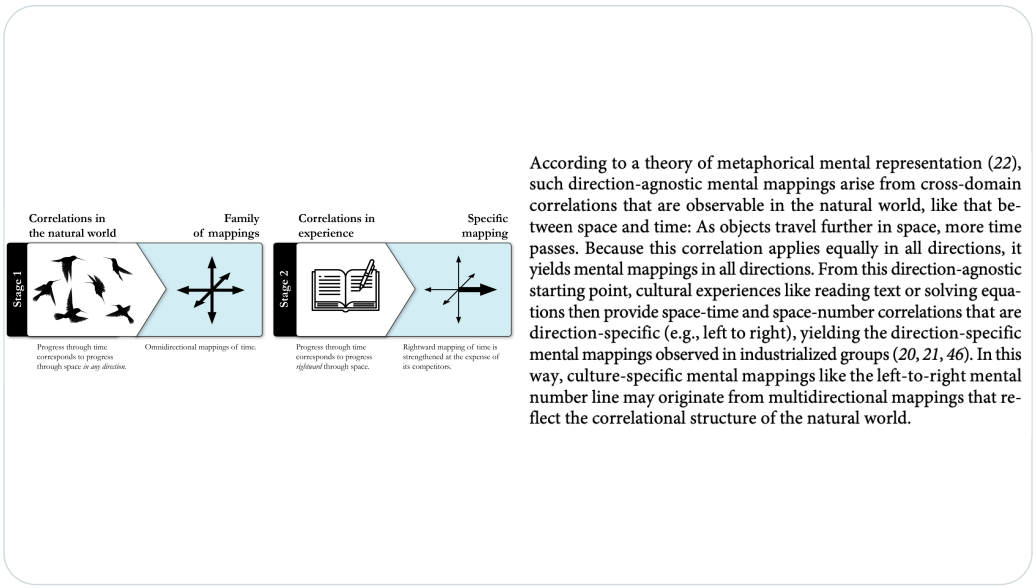
This inconsistency within individual participants is really hard to explain if there is a single mental magnitude line that codes all of these domains the same way.

Second, the mappings we observed cannot be explained by a mental magnitude line, even one without a default direction. If different mappings reflected "the same coordinate system applied to all magnitudes" (*12*), then any coherent spatial mappings should have had the same direction in a given mind (*11*, *15*, *16*). They did not; even the most systematic mappings of size, time, and number regularly went in different directions in the same participant. Therefore, although a generalized magnitude system may explain why people tend to associate more in one domain with more in another (*43*, *44*), it does not explain the way people map these domains onto space (*45*).

1 7

Benjamin Pitt @BenPitt · Aug 13, 2021

In short, US kids and Tsimane' adults showed no evidence of a default directional bias or a mental magnitude line. Instead, mental mappings may begin with spatial structure but no consistent direction, as found in the natural world... casasanto.com/papers/Casasan...



According to a theory of metaphorical mental representation (*22*), such direction-agnostic mental mappings arise from cross-domain correlations that are observable in the natural world, like that between space and time: As objects travel further in space, more time passes. Because this correlation applies equally in all directions, it yields mental mappings in all directions. From this direction-agnostic starting point, cultural experiences like reading text or solving equations then provide space-time and space-number correlations that are direction-specific (e.g., left to right), yielding the direction-specific mental mappings observed in industrialized groups (*20*, *21*, *46*). In this way, culture-specific mental mappings like the left-to-right mental number line may originate from multidirectional mappings that reflect the correlational structure of the natural world.

1 1 10

Benjamin Pitt @BenPitt · Aug 13, 2021

Check out the full (open access) paper here: advances.sciencemag.org/content/7/33/e...

3 1 15