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# OBSERVATION

# Priming the Mental Time Line

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Growing experimental evidence suggests that temporal events are represented on a mental time line, spatially oriented from left to right. Support for the spatial representation of time comes mostly from studies that have used spatially organized responses. Moreover, many of these studies did not avoid possible confounds attributable to target stimuli that simultaneously convey both spatial and temporal dimensions. Here we show that task-irrelevant, lateralized visuospatial primes affect auditory duration judgments. Responses to short durations were faster when the auditory target was paired with left- than with right-sided primes, whereas responses to long durations were faster when paired with right- than with left-sided primes. Thus, when the representations of physical space and time are concurrently activated, physical space may influence time even when a lateralized, spatially encoded response is not required by the task. The time–space interaction reported here cannot be ascribed to any Spatial–Temporal Association of Response Codes effect. It supports the hypothesis that the representation of time is spatially organized, with short durations represented on the left space and longer ones on the right.

*Keywords:* time representation, temporal duration, space-time interactions, visuospatial attention, priming

Interactions between space, time, and numbers have become a major issue in cognitive science. These interactions suggest that the representation of both time and numbers might be deeply rooted in cortical networks that also subserve spatial cognition (Hubbard, Piazza, Pinel, & Dehaene, 2005; Umiltà, Priftis, & Zorzi, 2009; Walsh, 2003; also, see Dehaene & Brannon, 2010).

Space-number interactions have been widely attributed to a spatial representation of numerical magnitude, or Mental Number Line (MNL; Dehaene, Bossini, & Giraux, 1993; Zorzi, Priftis, & Umiltà, 2002). For example, when participants judge the magnitude or the parity of a digit, responses to small numbers (relative to the stimulus range or the reference number) are faster with the effector (e.g., a given hand or finger) that operates in the left space, whereas response to large numbers are faster with the effector that operates in the right space (Spatial Numerical Association of Response Codes (SNARC) effect; Dehaene et al., 1993). Recent studies have extended this paradigm to the time domain to investigate whether space also interacts with time, thereby supporting the hypothesis that temporal events would be spatially represented on a Mental Time Line (MTL; for a systematic review see Bonato, Zorzi, & Umiltà, submitted). The hypothesis that time concepts, such as past and future, are mapped onto spatial locations, initially grounded in the observation that people use spatial metaphors to think about time (Lakoff & Johnson, 1980), has found considerable empirical support (e.g., Boroditsky, 2000; Casasanto & Boroditsky, 2008; Miles, Nind, & Mcrae, 2010; Santiago, Lupiáñez, Pérez, & Funes, 2007). However, a number of recent studies have investigated space-time interactions using a more basic dimension of time, that is, temporal duration (see below). The latter is also the focus of the present study.

Most of the studies reporting an interaction between space and temporal duration used some variant of the SNARC paradigm (e.g., Conson, Cinque, Barbarulo, & Trojano, 2008; Ishihara, Keller, Rossetti, & Prinz, 2008; Vallesi, Binns, & Shallice, 2008, Experiment 1). In the numerical domain, however, the idea that the SNARC effect implies a spatial representation of numbers is disputed (e.g., Gevers, Verguts, Reynvoet, Caessens, and Fias, 2006; Proctor & Cho, 2006; Santens & Gevers, 2008). For exam-

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ple, Proctor and Cho (2006) argued that in binary choice tasks, stimulus and response alternatives are encoded with either positive or negative polarities and response selection is faster when the polarities match than when they do not. Thus, the SNARC effect would be explained in terms of match/mismatch between polarity of number magnitude (negative for small) and polarity of spatial response codes (negative for left). A similar explanation could be invoked to account for the SNARC-like effect in the time domain. Finally, two studies reporting space–time interactions used experimental paradigms in which the spatial and the temporal dimensions were conveyed within the same stimuli. Casasanto and Boroditsky (2008) showed that the ability to reproduce the temporal duration of growing/stationary lines or moving dots was influenced by their spatial extent. In Vicario et al. (2008), participants' judgments of temporal duration were influenced by the horizontal spatial location (left, center, or right) of the stimuli (digit or dots). Note that the response was also spatially coded (left/right button press).

The aim of the present study was to assess whether temporal duration is spatially represented on a horizontal MTL if the confounds attributable to spatial response coding and dimensional overlap of space and time within the stimuli are simultaneously removed from the experimental paradigm. For this purpose, we adapted the visuospatial priming paradigm developed by Stoianov, Kramer, Umiltà, and Zorzi (2008), who investigated whether space–number interactions can take place when perceptual and numerical spatial representations are concurrently activated. In their study (also see Kramer, Stoianov, Umiltà, & Zorzi, 2011), an irrelevant visuospatial prime was presented on the left or right side of the display, while participants responded verbally to indicate the magnitude or parity of a target digit presented at a central fixation. Stoianov et al. found an interaction between prime location and numerical magnitude, consistent with a left-to-right oriented MNL. Moreover, the irrelevant prime was more effective when it followed (backward priming) than when it preceded (forward priming) the target. There is only one previous study that used a paradigm similar to ours (and to that of Stoianov et al., 2008) to investigate space–time interactions. Vicario, Rappo, Pepi, and Oliveri (2009, Experiment 2) asked participants to judge temporal duration of auditory stimuli (using spatially encoded responses), while lateralized visual distracters were presented immediately after the target offset (i.e., backward priming).[1] The results did not show any significant effect of the visuospatial distracters.

We asked participants to orally respond in a duration judgment task on auditory stimuli (i.e., tones), while irrelevant visuospatial primes were presented either on the left or the right side of the display. The primes were presented both in forward and backward priming conditions. In sum, our experimental paradigm had two key features: (i) the task did not involve spatially encoded responses to avoid any SNARC-like effect, and (ii) primes and targets were completely orthogonal to each other with reference to the spatial and the temporal dimensions.

## Method

### Participants

Eighteen students of the University of Padova (12 females and six males, mean age: 23.2) took part in the study. They provided their informed consent and received a small fee for their participation. The study was approved by the local Ethics Committee.

### Apparatus and Stimuli

Visual stimuli, white on a black background, were generated on an IBM-compatible Pentium III computer using E-prime (Psychology Software Tools, Pittsburgh, PA), and were presented on a 17″ LCD monitor. Visuospatial primes (a filled circle of 1° diameter) appeared 4° to the left or to the right of a central fixation dot (diameter: 0.2°). Auditory stimuli consisted of 440-Hz sinusoidal tones. The duration of the reference tone was set at 350 ms, whereas the target tone could last for 200, 250, 300, 400, 450, or 500 ms. Eye position was monitored using a QuickClamp eyetracking system (Arrington Research Inc., Scottsdale, AZ) recording pupil and corneal reflection position at 60 Hz. Correct fixation was defined in terms of a circular 1° radius around the fixation dot.

### Procedure

Participants sat at 57 cm from the monitor and positioned their head in a stationary chinrest. Each trial started with the fixation dot. When the eyetracker detected correct fixation for 500 ms, the reference tone was presented. After 1000 ms from the offset of the reference tone, a target tone was presented. Visuospatial priming was obtained by presenting the prime for 100 ms either to the left or to the right of fixation. On half of the trials, prime onset occurred 100 ms before target onset (forward stimulus onset asynchrony, SOA, condition); on the other half, it occurred 100 ms after target onset (backward SOA condition). Each trial terminated after 1350 ms from target presentation or immediately after a response was executed. During the intertrial interval a blank display of random duration (1.8–2.2 s) was presented.

Participants were asked to perform a duration judgment task while maintaining central fixation. Participants responded orally by using two arbitrary nonwords: half of the participants were instructed to respond "Ti" if the target duration was shorter than that of the reference tone and "To" if it was longer, whereas the other half had the opposite assignment. The use of two nonwords with the same initial consonant removed any timing bias in activating the voice-key (which would be present if "shorter" and "longer" were used to respond). The instructions stressed both accuracy and speed. Participants received a practice session of 14 trials, followed by a block of 336 experimental trials (6 target durations $\times$ 2 spatial positions of the prime $\times$ 2 priming SOAs $\times$ 14 replications). Each participant received a different randomized trial sequence.

## Results

Trials in which ocular movements occurred were excluded from the analysis (7.85%). We measured the reaction time (RT) from the offset of the target tone. We considered only correct trials with

[1] Strictly speaking, the notion of backward priming applies only when a prime is presented before target processing is complete. Indeed, in Stoianov et al. (2008) there was a partial temporal overlap between backward prime and target.

RTs no shorter than 200 ms, no longer than 1000 ms. Then we excluded RTs below and above two standard deviations from the mean, for each participant and condition (Miller, 1988; Ratcliff, 1993). The percentage of discarded trials was 3.91%.

We labeled as congruent the trials in which a left-sided prime was paired with a short target duration (i.e., shorter than the reference of 350 ms) or a right-sided prime was paired with a long target duration. Right-short and left-long pairings were labeled as incongruent trials. We computed the absolute distance (ms) between reference tone duration (i.e., 350 ms) and target tone duration (i.e., 200, 250, 300, 400, 450, and 500 ms) and entered mean RTs into a repeated-measures analysis of variance (ANOVA) with SOA (forward vs. backward), Congruence (congruent vs. incongruent), and Distance (50, 100, and 150 ms) as factors. The ANOVA revealed a main effect of SOA, $F(1, 17) = 7.46$, $p = .01$, $\eta_p^2 = .31$. Responses were faster when the prime was presented before target onset (forward priming: 490 ms) than after it (backward priming: 506 ms). Crucially, there was a main effect of Congruence, $F(1, 17) = 6.25$, $p = .02$, $\eta_p^2 = .27$. Responses were faster on congruent (493 ms) than on incongruent trials (503 ms). The effect of Distance was also significant, $F(1.17, 19.89) = 6.79$, $p = .01$, $\eta_p^2 = .29$, Greenhouse-Geisser corrected. A significant linear contrast, $F(1, 17) = 6.92$, $p = .02$, $\eta_p^2 = .29$, suggested that RTs decreased with the increase of the absolute duration distance (in ms) between the target and the reference tone (Figure 1A). No significant interactions emerged.

Error rates (arcsine transformed) were also analyzed as a function of SOA (forward vs. backward), Congruence (congruent vs. incongruent), and Distance (50, 100, and 150 ms). The repeated measure ANOVA revealed a main effect of Distance, $F(1.75, 24.48) = 58.51$, $p < .0001$, $\eta_p^2 = .81$ Greenhouse-Geisser corrected (Figure 1B). A significant linear contrast, $F(1, 14) = 83.57$, $p < .0001$, $\eta_p^2 = .86$, suggested that error rates decreased with the increase of the absolute duration distance (in ms) between the target and the reference tones. The two-way interaction between SOA and Congruence just missed significance, $F(2, 34) = 71.63$, $p = .058$, $\eta_p^2 = .2$, as well as the three-way interaction between SOA, Congruence, and Distance, $F(2, 34) = 31.38$, $p = .056$, $\eta_p^2 = .16$. Follow-up *t* tests (one-tailed, Bonferroni corrected) revealed that the difference between congruent and incongruent conditions was significant only in the backward SOA condition at the intermediate distance (i.e., 100 ms), $t(17) = 2.67$, $p = .008$ (Figure 1B).

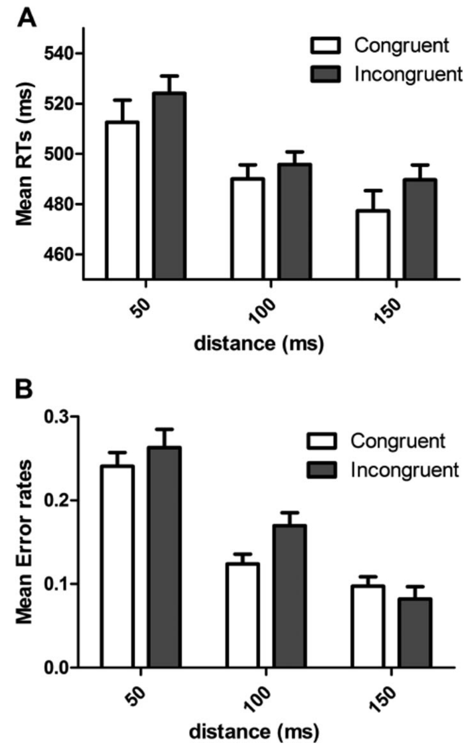


*Figure 1.* (A) Mean RTs (ms) for the duration judgment task as a function of congruence (congruent trials vs. incongruent trials) and distance (ms) between reference tone duration (i.e., 350 ms) and target tone duration (i.e., 200, 250, 300, 400, 450, and 500 ms). Data are collapsed across type of priming (forward vs. backward). (B) Mean error rates for the backward priming condition as a function of distance and congruence. Error bars in both graphs indicate one standard error of the mean, corrected for within-subjects designs (Cousineau, 2005).

## Discussion

We investigated the influence of visuospatial processing on auditory temporal processing, using the priming paradigm introduced by Stoianov et al. (2008) in the numerical domain. Response latencies and accuracy in the duration comparison task decreased with increasing distance (in ms) between the duration of the target tone and that of the reference tone. The distance effect is thought to reflect analog magnitude representations, where stimuli that are closer (i.e., more similar) in representational space are more difficult to discriminate than stimuli that are further apart (Moyer & Landauer, 1967, for numerical stimuli; Wearden & Lejeune, 2008, for temporal stimuli). Crucially, performance was also modulated by the congruence of the visuospatial primes: responses to short durations were faster when the auditory target was paired with left- than with right-sided primes, whereas responses to long durations were faster when paired with right- than with left-sided primes. Congruency also modulated the error probability in the backward priming condition, at least when the temporal distance between target and reference was intermediate. Therefore, our results support the hypothesis of a horizontal MTL, with relatively short durations positioned on the left and longer durations on the right, using an experimental paradigm that does not involve spatially encoded responses (thereby avoiding any SNARC-like effect) and where the spatial dimension is both task-irrelevant and orthogonal to the judged temporal dimension. Note that what is left or right is not tied to an absolute duration value but to the reference stimulus (350 ms in the present study). This is well known in the numerical cognition literature (e.g., Dehaene et al., 1993; Fias, Brysbaert, Geypens, & d'Ydewalle, 1996), and previous studies on time–space interactions have shown that the same applies to the time domain, both for suprasecond (e.g., Conson et al., 2008) and subsecond time intervals (e.g., Vicario et al., 2009).

Our results mirror those of Stoianov et al. (2008; see also Kramer et al., 2011) in the numerical domain. However, spatial position of the prime modulated RTs in both forward and backward priming conditions in our study, whereas only backward priming was effective in their study. Stoianov et al.'s explanation of the latter finding was that processing the numerical magnitude of the target (which also implies perceptual processing of the digit) is much slower than processing the location of the visuospatial prime. This was not the case in our study, because processing of target duration started right at the onset of the tone. Nonetheless, we found that congruency of the spatial prime affected accuracy only in the backward priming condition (intermediate distance), thereby suggesting that forward priming is less effective. As noted in the Introduction, Vicario et al. (2009) failed to observe any effect of lateralized visual distracters on temporal duration judgments for auditory stimuli. The visual distracters immediately followed target *offset* in their study. In contrast, we presented the visuospatial primes 100 ms after target *onset* in our backward priming condition. This might suggest that visuospatial priming was effective in our study because the prime overlapped in time with the processing of target duration.

The congruency effect might also be explained by the polarity coding account of Proctor and Cho (2006) if we assume that long durations are coded as positive and short durations as negative (in analogy to their proposal for numbers). This code would then produce match or mismatch with the polarity of the primes, coded as positive for right and negative for left. However, this alternative account does not fit well with the importance of the relative timing of prime and target presentation across the various studies (including ours) that used visuospatial priming in the numerical and temporal domains (Kramer et al., 2011; Stoianov et al., 2008; Vicario et al., 2009).

The precise mechanism underlying our visuospatial priming effect remains to be investigated. One possibility is that space–time interactions depend on functional overlap between the representation of space and the time domains, which might be attributable to a shared neural substrate for magnitude coding (Bueti & Walsh, 2009; Srinivasan & Carey, 2010; Walsh, 2003). Understanding the nature of the priming effect (facilitatory vs. inhibitory) may help in clarifying this issue. In the numerical domain, Kramer et al. (2011) observed that visuospatial priming had an inhibitory nature with respect to a no-cue condition. A similar finding in the temporal domain would be at odds with the hypothesis of functional overlap. Moreover, a dissociation between temporal and physical spaces is suggested by neuropsychological evidence of intact space processing combined with a specific impairment of time processing (Cappelletti, Freeman, & Cipolotti, 2009). Alternatively, the effect induced by the spatial primes fits well with the evidence that time processing is biased by the allocation of spatial attention (Frassinetti et al., 2009; Vicario et al., 2007). That is, orienting of visuospatial attention might enhance a specific side of physical space, which, in turn, might enhance the corresponding side of temporal space.

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