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The Combination of the Horizontal and Vertical Dimensions in Mental Time Representation: The Existence of a Spatial Mental Map of Time

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ABSTRACT

Horizontal and vertical representations of time (past-left or down and future-right or top) have been demonstrated. However, there are only few studies investigating the existence of a spatial map of time, considering it as the interaction of different spatial dimensions in space. The aim of this study is to investigate the existence of a mental time representation along the diagonal axes, intended as the combination of the horizontal and the vertical dimensions. 79 Italian participants (85% females; mean age: 25.11 ± 4.86 years; 77 right-handed) performed an online temporal judgment task using 20 Italian temporal expressions presented always in the center (Experiment 1) or in the four corners of the screen (Experiment 2) and two pairs of response keys ("C" and "U" for the positive diagonal; "R" and "N" for the negative diagonal). Results showed spatial-temporal associations in positive (i.e., time was represented from left-bottom to right-top) and negative (i.e., time was represented from left-top to right-bottom) diagonals, although in the Experiment 2 these associations were weak for the negative diagonal. These spatial-temporal associations along both diagonals were confirmed even when participants were free to place different temporal stimuli along a diagonally drawn line, in a Time-to-Position task, indicating that the temporal expressions could be ordered linearly along the diagonal spaces. Finally, these data indicated that the horizontal information was mainly involved for determining the spatial-temporal associations along both diagonals, whereas the vertical information was flexible with a bottom-to-top (for positive diagonal) and top-to-bottom (for negative diagonal) temporal representation.

Keywords: Time-Space Congruency Effect; Horizontal Space; Vertical Space; Diagonals; Mental Map of Time Representation

Introduction

Is the existence of a spatial map of time in human mind possible? According to the literature, the abstract concept of time is expressed in terms of a more concrete domain as the space, assuming the metaphorical mapping view (Boroditsky, 2000; Lakoff & Johnson, 2003). This view can improve the knowledge of the time structuring and processing in human mind. It has been widely demonstrated that people represent time through an association with different spatial locations. Specifically, it has been found that time is represented along horizontal (Bonato et al., 2012; Di Bono et al., 2012; Ouellet et al., 2010; Santiago et al., 2007; Torralbo et al., 2006; Weger & Pratt, 2008), vertical (Beracci et al., 2021; Beracci & Fabbri, 2022; Bergen & Chan Lau, 2012; Boroditsky et al., 2011; Chen, 2007; Dalmaso et al., 2022; Fuhrman et al., 2011; Gu & Zhang, 2012; Leone et al., 2018) and sagittal (Casasanto & Jasmin, 2012; Hartmann & Mast, 2012; Núñez & Cooperrider, 2013; Starr & Srinivasan, 2021; Teghil et al., 2021; Ulrich et al., 2012) axes. This spatial-temporal association is known as "*Spatial-Temporal Association of Response Codes*" or STEARC effect (Ishihara et al., 2008), and it indicates a past-left and future-right (Bonato et al., 2012) mapping horizontally, a past-bottom and future-top top (Beracci et al., 2021, 2022; Dalmaso et al., 2022; Leone et al., 2018) or a future-bottom and past-top (Bergen & Chan Lau, 2012; Boroditsky et al., 2011; Dalmaso et al., 2022; Fuhrman et al., 2011; Gu & Zhang, 2012) mapping vertically, and a past-back and future-front (Ulrich et al., 2012) mapping along the sagittal space. Additionally, the STEARC effect was found not only in studies using temporal durations (Dalmaso et al., 2022; Fabbri et al., 2013a, 2013b; Ishihara et al., 2008; Vallesi et al., 2008) but also with different types of stimuli as past- and future-related written targets (e.g., events or temporal expressions) presented on a screen (Arzy, Adi-Japha, et al., 2009; Arzy, Collette, et al., 2009; Boroditsky, 2001; Chen, 2007; Hartmann & Mast, 2012; Leone et al., 2018; Santiago et al., 2007; Weger & Pratt, 2008) or pictures, stickers and photographs showing a temporal sequence, as breakfast, lunch and dinner times or actor photographs at the different ages (Arzy, Collette, et al., 2009; Bergen & Chan Lau, 2012; Fuhrman & Boroditsky, 2010; Tversky et al., 1991; Woodin & Winter, 2018), suggesting that the spatial-temporal association is a strategic way to understand and process different temporal information. However, it remains to understand in which way (and whether) the different spatial-temporal associations, along the different spatial dimensions, could interact each other. For example, it remains to explore the possibility that the horizontal and vertical representation of time could interact for a diagonal representation of time.

This question could derive from numerical domain, which is another abstract concept usually processed using a spatial metaphor. As for temporal information, in the numerical domain, a SNARC (*Spatial-Numerical Associations of Response Codes*) effect has been found (e.g., Dehaene et al., 1993), with a specific characterization for horizontal (small numbers in the left and large numbers in the right space) and vertical (small numbers in the bottom and large numbers in the up space) dimension, suggesting the existence of a mental number map (Dehaene et al., 1993; Hubbard et al., 2005; Lourenco & Longo, 2010; Schwarz & Keus, 2004; Wood et al., 2008), as the result of the involvement of different axes (Winter et al., 2015). For example, Hesse and Bremmer (2017) measured saccadic responses induced by auditorily or visually presented numbers along four axes: horizontal, vertical, first diagonal (from bottom-left to top-right; here called “positive” diagonal) and second diagonal (from top-left to bottom-right; here called “negative” diagonal). Results showed that small numbers were associated with the left and the bottom space, whereas large numbers were associated with the right and the top space, along the positive diagonal in a combination of horizontal and vertical number representations (Hesse & Bremmer, 2017). Similarly, in Loetscher et al. (2010) study, participants looked to the bottom-left when they had a small number in mind and to the right-top when they had a large number in mind, relative to a previous stated number. These studies are instances of the horizontal and vertical mental number representation and of how the combination of both cardinal axes determine a preference for “positive” (from left-bottom to right-top) diagonal. This preference probably could derive from the spatial “congruency” determined horizontally by the associations between left and small number and between right and large number and vertically by the associations between bottom and small number and between top and large number. These assumptions were demonstrated by Gevers Lammertyn, Notebaert, Ferguts and Fias (2006). Indeed, the authors, in a parity judgement task, investigated the SNARC effect (Dehaene et al., 1993) when both horizontal and vertical dimensions were involved. Participants pressed the central key (5) to start the trial and then had to response with the downward-left (1) or upper-right (9) keys or with the upper-left (7) or downward-right (3) keys of a numerical keypad. Results showed a SNARC effect along a positive diagonal with faster responses and more accuracy for small numbers with a downward left-key and for large numbers with an upper-right key, according both the horizontal and vertical dimensions, suggesting a mental number representation along different axes combined in the space (Gevers et al., 2006) and a preference for the “positive” diagonal, probably derived from the congruency between horizontal and vertical numerical representations. In a similar way to what has been found in numerical domain, it is possible to advance the idea that a mental time map could exist as the result of two different axes.

To the best of our knowledge, in the temporal domain, there are only few studies exploring the mental time representation along different axes and their combination in similar way to what has been done using numerical material. For example, Hartmann, Martarelli, Mast and Stocker (2014), following the procedure provided by Loetscher et al. (2010) with numbers, investigated the mental timeline asking participants to perform an episodic mental travel displacing themselves in their subjective past and future while their eye movements on a blank screen were measured. In particular, participants had to think their personal life circumstances (e.g., “*what you did*” or “*what you will be doing in a typical day*”) in the past or in the future (e.g., “*one year back in the past or one year in the future*”), trying to remember or imagine the episodes with many details possible (Hartmann et al., 2014). The results showed that many participants moved their gaze rightward and upward at the same time, moving from the past to the future, showing a diagonal mental time representation in similar way to what has been reported with numbers by Loetscher et al. (2010). This result could suggest that the concept of a horizontal and vertical mental line should be extended to a “mental time space” (Hartmann et al., 2014) or time map. In addition, the previous findings could indicate that participants, when they though to the future, combine the horizontal (future is right) and vertical (future is up) information. However, Topić, Stojić and Domijan (2021) recently tried to explore this (hypothesized) mental time map with an implicit go/no-go task. After a presentation of a target object (e.g., a peach, an orange, or a tomato) for a variable duration in milliseconds (300, 600, 1200 or 1500 ms), participants had to search for the designated object as fast as possible, in a search array 7x7. In this way, it was possible to present the target in different spatial positions, covering horizontal, vertical, and both diagonals. In the go trial, participants had to press the central button with their dominant hand when they found the target and reaction times was defined as the time elapsed between the presentation of the search array and the button press. In case of no-go trials, there was no target in the search array and participants required to refrain from responding. Successively, the authors performed separate analysis on the horizontal, vertical and two diagonal axes. In the horizontal analysis, they computed the mean reaction times (RTs) for the right space and subtracted it from mean RTs of the left space, but the results did not show significant association on the horizontal axis. In the vertical analysis, they computed the mean RTs for the top space and subtracted it from mean RTs of the bottom space and results showed a significant vertical space-time association, suggesting a mental time representation with the shorter durations on the top and the longer durations on the bottom. In the negative (from left-top to right-bottom) diagonal analysis, the mean RTs for the right-bottom was subtracted from the mean RTs of the left-top space and results showed a significant association, showing a negative diagonal mental timeline (from left-top to right-bottom). In the positive (from left-bottom to right-top) diagonal analysis, the mean RTs for the left-bottom space was subtracted from the mean RTs of the right-top space and the results did not show a significant space-time association. As before, this study could indicate that the diagonal representation of time resulted from a combination of horizontal (left-right) and vertical (top-bottom) temporal processing, although the authors found a negative (from left-top to right-bottom), instead of a positive, diagonal time representations. Topić et al. (2021) discussed their findings, claiming that the experience with the law of gravity that pulls everything from top to the bottom could determine this time map (Topić et al., 2021). However, Topić et al. (2021) did not replicate the horizontal left-to-right timeline using an implicit task (but see Di Bono et al., 2012, for a horizontal space-time congruency effect with an implicit task), and, thus, it remained to understand, from one hand, how and which way the horizontal information was added in the negative diagonal representation, and, on the other hand, the dominance relationship between horizontal and vertical information. Indeed, for the study by Hartmann et al. (2014), both horizontal and vertical dimensions equally contributed to the positive diagonal, whereas, for the study by Topić et al. (2021) the vertical axis seemed to be dominant (respect to horizontal axis) or the unique space to be considered for the negative diagonal. In line with this last assumption, recently, Sun et al., (2023) displaying figures in temporal order (e.g., young Di Caprio and the actual Di Caprio) along positive and negative diagonals, found that English speakers preferred the positive diagonal whereas the Mandarin speakers preferred the negative diagonal arrangement. These results seemed to indicate that the vertical component of the diagonal representation differed from Western and Eastern cultures. Gu and Zhang (2012) showed the dominance of a mental time representation along the horizontal compared to the vertical axis, investigating whether Mandarin speakers employed both the horizontal and vertical representations of time and which kind of representation of time was dominant. In their study, participants had to perform a temporal categorization task of words by pressing numerical keys (lower-left: 1, lower-right: 3, upper-left: 7 and upper-right: 9) of a numerical keyboard. After demonstrating the presence of spatial-temporal associations along the horizontal and vertical dimensions (Experiment 1), with the presence of a left-to-right and top-to-bottom STEARC effect, they investigated how these two spatial representations interacted with each other. Indeed, in a second experiment, the responses keys were assigned in a left-diagonal (lower-right and upper-left; keys 7 and 3) and a right-diagonal (lower-left and upper-right; keys 1 and 9) axes. For the left-diagonal (or negative diagonal), a STEARC effect was observed in both the horizontal (left-right) and vertical (top-bottom) dimensions. On the other hand, for responses in the right-diagonal (or positive diagonal), a STEARC effect was observed only in the horizontal axis, demonstrating ad advantage of the horizontal dimension when both axes were activated at the same time (Gu & Zhang, 2012). Using an explicit task (i.e., the temporal information was relevant for the task), Gu and Zhang (2012) seemed to indicate that the negative diagonal resulted from the “congruent” combination of both horizontal (left-right) and vertical (top-bottom) axes, while the positive diagonal only resembled the horizontal left-to-right time representation, suggesting that the bottom-past and top-future associations were more linked to (or derived from) the left-to-right direction of mental time representation. Considering that Sun et al. (2023) proposed a vertical bottom-to-top direction of mental time representation, especially in English participants, it was possible to advance the idea that, in Western culture, a preference for a positive diagonal should be expected, due to the congruency between left-to-right and bottom-to-top time mappings, whereas the negative diagonal should derive from the dominance of left-to-right horizontal time mapping, mirroring the findings proposed by Gu and Zhang (2012).

Considering the contrasting results reported by Hartmann et al. (2014) and Topić et al., (2021)’ studies, both using an implicit task, as well as the dissociating findings along both diagonals reported by Gu and Zhang (2012) and Sun et al. (2023), the aim of the current study was to investigate the presence of a mental time representation along the diagonal dimension, considering it as the combination of the horizontal and the vertical dimensions. Indeed, participants were asked to perform an online[1] temporal judgement task using 20 Italian temporal expressions (10 past and 10 future; see Appendix in Beracci, Santiago et al., 2022; Beracci & Fabbri, 2022) presented on the center (Experiment 1) or in the four corners of the screen (Experiment 2) and two pairs of response keys of a standard keyboard along the positive (“C” [left-bottom] and “U” [right-top] keys) and negative (“R” [left-top] and “N” [right-bottom] keys) diagonal axes were pressed to respond. According to what has been reported for numerical domain (Hesse & Bremmer, 2017; Loetscher et al., 2010), a significant space-time association along a unique diagonal dimension should be expected, with a difference between positive and negative diagonal. This expectation could be due to the fact that our participants performed an explicit temporal judgment task in which we expected to find a mental time representation along the positive diagonal only, intended as a combination of the horizontal, from left to right, and the vertical dimension, from bottom to top. This assumption was based on the preference for a bottom-to-top vertical time representation in Western culture (i.e., the study was conducted with Italian participants) due to daily experience along this vertical orientation, such as the growth process of a child to adulthood, or of a seedling to a plant, or the arrangement of buildings with several floors from the ground floor to the attic, in line with the “more-is-up” metaphor (Gu & Zhang, 2012; Hartmann et al., 2014; Lakoff & Johnson, 2003; Sun et al., 2023). In line with the study by Gu and Zhang (2012), a time representation

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[1] This study was performed online due to the worldwide health emergency caused by the COVID-19 and the consequently home confinement and social isolation imposed by Italian government.

along the negative diagonal should only be due to the dominance of horizontal dimension respect to vertical one. To best of our knowledge, no studies attempted to directly replicate the study by Gu and Zhang (2012) and it should be expected to find a STEARC effect along the positive diagonal space only, with a combination of the horizontal (left-to-right) and vertical (bottom-to-top) dimension. Although in the literature mixed results for the vertical STEARC effect has been reported (see the introduction in Beracci & Fabbri, 2022 for a comprehensive review of the topic), the bottom-to-top orientation of time mapping along the vertical axis seems to be preferred in Western culture.

To reach this aim, in two experiments, our participants performed a temporal judgment task (explicit bimanual speeded task) and a Time-to-Position task (explicit free task). In this latter task, we required participants to place all the temporal expressions along a diagonal line (see Beracci, Santiago et al., 2022 and Beracci & Fabbri, 2022, for the same procedure along the horizontal and vertical dimensions, respectively). Specifically, we used a single diagonal line from left-bottom to right-top in the positive diagonal and a single diagonal line from left-top to right-bottom in the negative diagonal as a visual cue for arranging the temporal expressions. In this way, we should replicate and extend the results reported in the temporal judgment task, given that participants did not perform a binary manual response, but they were free to place along the line the temporal expressions, resembling in a more indirect way, task instruction provided by Hartmann et al. (2014). Also, this additional task allowed us to deeper understand the nature of the expected diagonal time representation. Given that participants were free to place along a visual diagonal line the temporal expressions, two possible behavioral patterns could be expected. From one hand, all past expressions were placed on the left-bottom (or left-top) side of the line and all future expressions were placed on the right-top (or right-bottom) side of the line, suggesting that the diagonal representation of time was mainly determined by task setting (e.g., response keys diagonally displayed or a visual diagonal line).

On the other hand, the temporal expressions were placed along the line with a specific order, suggesting that participants, probably, were induced to "travel" along the diagonal line for performing the task, although we provided them a visual diagonal. Indeed, the presence of the visual line could not necessary "force" participants to order temporal expressions along the line because the temporal expressions did not refer to any temporal durations, but they were usually used to refer to different time periods, which are not necessary ordered. For example, the expressions "*early*" and "*recently*" could be both used for referring to 5 minutes or 1 hour or 1 day ago. However, if participants placed these expressions in order, then, probably, this order could reflect a "temporal difference" between these two expressions for participants who used these expressions for referring to different time periods. Thus, this task could give further insight for the diagonal representation of time. Finally, our Time-to-Position task could be considered a more complete task than that used in previous studies, which used simple ordered pictures (e.g., breakfast, lunch dinner for Tversky et al., 1991 or young, actual and future Di Caprio for Sun et al., 2023), allowing us a better understanding of mental time line.

Experiment 1

The aim of this Experiment was to investigate the presence of a diagonal mental time representation, using a temporal judgement task. Specifically, the past and future temporal expressions (e.g., "*recentemente*" or "*presto*"; in English "*recently*" or "*early*") were presented at the center of the screen each time. The participants performed the temporal task four times (twice along the positive diagonal and twice in the negative diagonal), with two pairs of response buttons of a standard keyboard, representing diagonal space. As stated above, it should be expected a STEARC effect along positive diagonal, intended as the combination of the horizontal and vertical dimensions, supporting a mental time map.

Participants

We recruited a group of 41 Italian students (35 females; mean age = 24.34 ± 3.39 years) for participation in an online study, in exchange for course credits, on the basis of the statistical power analysis performed by Beracci and Fabbri (2022), with G*Power 3.1 (Erdfelder et al., 1996) , on data from a meta-analysis assessing the space-time congruency effect (von Sobbe et al., 2019). With an $a = .05$ and power = .80, the projected sample size needed with an effect size of .46 was approximately N = 12 for the within-group comparison, keeping Type I error at the desired level of 5%, with a high statistical power (80%). In the present study we decided to recruit more participants than those requested by power analysis in order to align our sample size to that reported in previous studies addressing the same aim of the present study (mean N was about 36 participants, ranging from 19 in Hartmann et al., 2014 to 90 in Sun et al. 2023). In addition, this choice was grounded on the online study performed during the home confinement imposed by Italian government, and thus a large sample could reduce the error produced by the lack of full control during online study. The participants filled in the Edinburgh Handedness Inventory (EHI; Oldfield, 1971). Based on the EHI scores, 40 participants were right-handed (M = 86.09; SD = 31.11) and 1 was left-handed (M = -77.78). Data from 2 participants (2 females) were not included because we considered as exclusion criteria of outliers a maximum acceptable percentage of errors of 20% (see Grasso et al., 2022 for similar exclusion criteria of outliers). Thus, the data for the remaining 39 participants (33 females; mean age = 24.36 years; SD = 3.45 years; 38 right-handed) were analyzed. All participants had normal or corrected-to-normal vision and were not informed to the purpose of the study. Informed consent was obtained from all individual participants included and the study was approved by the Ethical Committee of the Department of Psychology at the University of Campania “Luigi Vanvitelli”.

Apparatus and Stimuli

An online data collection was performed using the online version of the E-Prime 3.0 software (Schneider et al., 2012). The reaction time experiment was executed after it was downloaded onto the participant's computer, which meant that the participant's internet speed did not affect reaction times in any way. We used the option to exclude mobile devices (phones and tablets), which are known to have an unreliable reaction time measurement. Stimuli consisted in the 20 temporal expressions (10 referring to the past and 10 referring to the future; see Appendices in Beracci & Fabbri, 2022 and Beracci et al., 2022). All stimuli were presented in the browser window and responses were measured using a regular keyboard ("C" and "U" or "R" and "N" keys).

Procedure

The experimental session had two parts, for a total duration of approximately 30 minutes. In the first part (positive diagonal), participants were required to categorize the target expressions as referring to the past or to the future and presented always centrally, using the "C" and "U" keys of a standard keyboard as response buttons. In each trial, a fixation cross (+) symbol was presented first at the centre of the screen for 1000 ms, followed by a temporal expression for 5000 ms or until a response was recorded. All target stimuli were presented in two separate blocks with different time–key mappings. In one block, the "C" key was pressed with the left hand in order to categorize the target as past, and the "U" key with the right hand to categorize the target as future. The other block had the reverse mapping. In the second part (negative diagonal), participants were required to perform the same task but using the "R" and "N" keys. The trial sequence was similar to what was described in the first part. In one block, the "R" key was pressed with the left hand in order to categorize the target as past, and the "N" key with the right hand to categorize the target as future. Then, the other block had the reverse mapping. The order of blocks was counterbalanced over participants. Each block comprised a total of 80 trials (four repetitions of each target expression) in a random order. Thus, altogether the participants judged 320 trials. Before the test, a 10-trial training block was run. The training phase could be repeated if requested by the participant. After each block, participant was allowed to take a short break. The order of positive and negative diagonals was counterbalanced across participants.

At the end of this task, participants were requested to perform the online Time-to-Position task using the online E-Prime 3.0 software. Participants had to perform the task twice. In the first part (positive diagonal), they had to place all the 20 temporal expressions along a diagonal 10cm-long line flanked by two labels "*passato lontano*" (in English: "*distant past*") at the left-bottom side and "*futuro lontano*" (in English: "*distant future*") at the right-top side. All temporal expressions were positioned centrally on the screen. In order to place each expression on the line, they had to move diagonally a circular cursor positioned centrally on the line with the mouse. Before to respond, participants read the instruction *"La parola da posizionare sulla linea è…* (In English: *"The word to position on the line is…""*) in order to show, in each turn, the target word to be positioned (Figure 1; left side). The second part of this task (negative diagonal) was the same of the first part, with the only exception that participants had to locate the temporal expressions along a diagonal 10cm-long line flanked by two labels "*passato lontano*" (in English: "*distant past*") at the left-top side and "*futuro lontano*" (in English: "*distant future*") at the right-bottom side (Figure 1; right side). The order of these Time-to-Position tasks was counterbalanced across participants in order to maintain a spatial correspondence between temporal decision and Time-to-Position tasks (i.e., if a positive diagonal condition was provided for speeded bimanual task, then a positive diagonal Time-to-Position task was further provided).

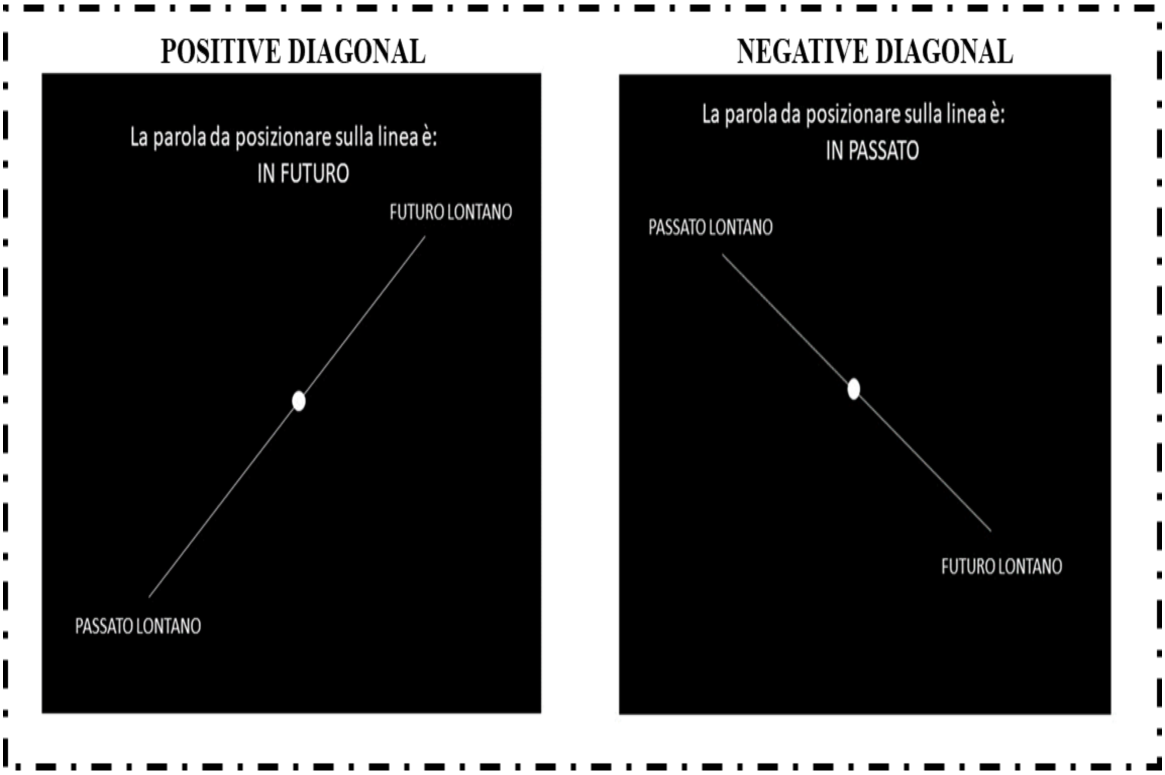

Figure 1. Example of the first part (positive diagonal; left side) and second part (negative diagonal; right side) of the online Time-to-Position task using the E-Prime software 3.0.

Data Analysis

Temporal judgement task

The mean reaction times (RTs) of correct responses were calculated using the software SPSS version 20.0 (IBM Corp.) To improve the internal validity of the study, RTs that were more than 3 SDs above or below the mean were discarded as outliers (about 1%).

First of all, a two-ways repeated measures ANOVA was carried out on RTs and accuracy (defined as number of errors or NEs), with Temporal Expression (past vs. future) and Response Position ("C" vs. "U") as within-subjects factors, in the positive diagonal and, Temporal Expression (past vs. future) and Response Position ("R" vs. "N") as within-subjects factors, in the negative diagonal. Successively, we merged the data of both diagonals and two

two-ways repeated measures ANOVAs were carried out on RTs and NEs with Temporal Expression (past vs. future) and Response Position (“C_R” as left vs. “N_U” as right keys and “C_N” as bottom and “R_U” as top keys) as within-subjects factors, separately for the horizontal and vertical dimension, in order to investigate the possibility of a dominant spatial orientation. When a reliable significance was found, the Bonferroni post-hoc test was run. The criterion set for statistical significance was $p < .05$ and we report the effect size (as eta partial square η^2_p).

Time-to-Position task

For the positioning task, firstly, we established the starting point of the diagonal line that was in the left-bottom side for the positive diagonal and in the left-top side for the negative diagonal (in correspondence of the label “*distant past*”). After identifying the starting point coordinates of the diagonal line (for the positive condition: X= 352, Y= 512; for the negative condition: X= 338; Y= 262), we measured the distance from the starting point of the line to the subjective mark positioned on the line (for whom we obtained x and y coordinates) with the cursor (i.e., Euclidean distance), for each participant and for each temporal expression. A linear fit model was then tested for describing the different distances from the starting point of each temporal expression.

Results

Temporal judgement task. All descriptive data for RTs and accuracy (with their relative standard deviations or SDs) are displayed in Table 1.

For the positive diagonal, the Temporal Expression x Response Position ANOVA on RTs revealed the significant interaction ($F(1,38) = 9.32$, $p = .004$, $\eta^2_p = 0.20$) with faster responses for the past with the “C” key (M= 984 ms; SD= 220 ms) than with the “U” key (M = 1077 ms; SD = 248 ms; $p = .005$ and for the future with the “U” key (M = 987 ms; SD = 272 ms) than with the “C” key (M = 1071 ms; SD = 240; *p* = .01), as showed in Figure 2a (see Table A1 in Appendix A in the Online Supplementary Materials (OSM) at: https://osf.io/yx9aq/?view_only=166720a36d3940bf8563146020b8507a for the same results obtained by linear mixed models (LMMs)). Results revealed no significant main effects (all *Fs* < 0.12 with *ps* $> .73$, $\eta^2_{ps} < 0.003$). The same ANOVA on NEs revealed the significant main effects Temporal Expression ($F(1,38) = 5.38$, $p = .03$, $\eta^2_p = 0.12$) and Response Position ($F(1,38) = 10.25$, $p = .003$, $\eta^2_p = 0.21$). Indeed, participants performed less errors for the future (M = 4.35; SD = 4.4) than for the past (M = 5.86; SD= 6.68) and with the “C” key (M = 3.43; SD = 3.85) than with the “U” key (M = 6.79; SD = 3.85). By contrast, the Temporal Expression x Response Position was not significant ($F(1,38) = 0.10$, $p = .75$, $\eta^2_{ps} = 0.003$) (Figure 2c).

For the negative diagonal, the Temporal Expression x Response Position ANOVA on RTs revealed the significant interaction ($F(1,38) = 7.20$, $p = .01$, $\eta^2_p = 0.16$) with faster responses for the past with the “R” key (M = 1019 ms; SD = 268 ms) than with the “N” key (M = 1125 ms; SD = 305 ms; *p*= .007) and for the future with the “N” key (M = 1055 ms; SD = 301 ms) than with the “R” key (M = 1131 ms; SD = 305; *p* = .05), as showed in Figure 2b (see Table A2 in Appendix A in the OSM (at: https://osf.io/yx9aq/?view_only=166720a36d3940bf8563146020b8507a) for the same results obtained by LMMs). Results revealed no significant main effects (all *F*s < 1.93 with *p*s $> .17$, $\eta^2_{ps} < 0.05$). The same ANOVA on NEs revealed neither significant main effects nor significant interaction (all *Fs* < 2.84 with *p*s $> .10$, $\eta^2_{ps} < 0.07$) (Figure 2d).

Table 1. Reaction times (RTs) in ms on and number of errors (NEs) (SDs in brackets) respectively for past and future temporal expressions selected with the “C” or “U” key, in the positive diagonal and, with the “R” or “N” key, in the negative diagonal, for the Experiment 1.

Positive Diagonal

Response Position	Temporal Expression			
	PAST		FUTURE	
	RTs	NEs	RTs	NEs
"C" KEY	984 ms (220 ms)	4.10 (3.99)	1071 ms (240 ms)	2.76 (3.71)
"U" KEY	1077 ms (248 ms)	7.63 (9.37)	987 ms (272 ms)	5.94 (5.09)

Negative Diagonal

Response Position	Temporal Expression			
	PAST		FUTURE	
	RTs	NEs	RTs	NEs
"R" KEY	1019 ms (268 ms)	5.51 (5.96)	1131 ms (305 ms)	5.96 (6.90)
"N" KEY	1125 ms (305 ms)	3.65 (4.29)	1055 ms (301 ms)	6.35 (7.14)

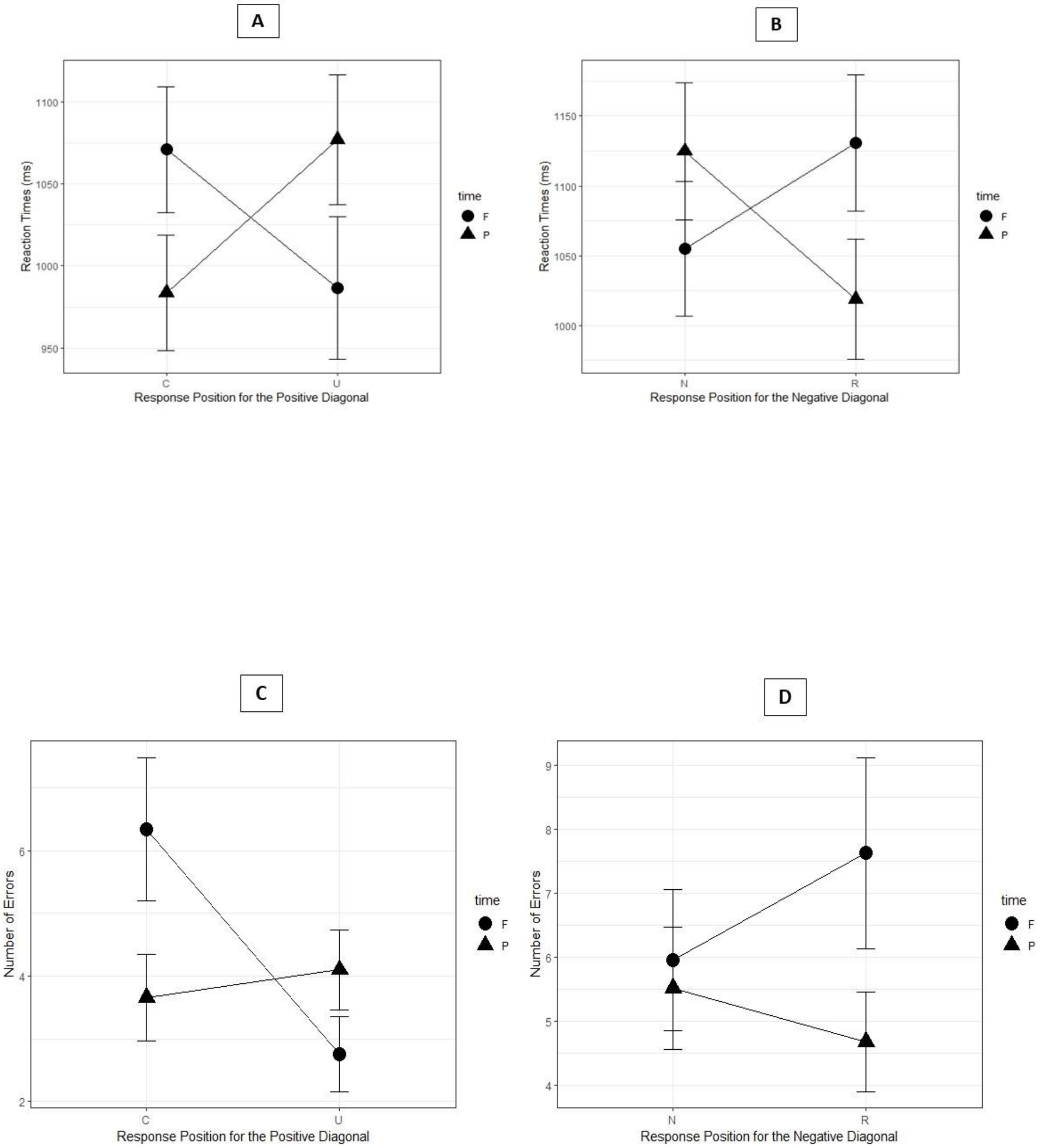

Figure 2. Mean Reaction Times (RTs, in ms) and number of errors (NEs), with the bars representing their SEs, for “C” and “U” keys (Fig. 2a for RTs and Fig. 2c for NEs) and for “R”

and “N” keys (Fig. 2b for RTs and Fig. 2d for NEs) when judging past and future target expression in Experiment 1.

Subsenquently, the Temporal Expression x Response Position ANOVA on RTs, considering only the horizontal dimension, showed a significant Temporal Expression x Response Position interaction ($F(1,38) = 14.15$, $p = .001$, $\eta^2_p = 0.27$). The same ANOVA on NEs revealed the same result (Temporal Expression x Response Position $F(1,38) = 4.91$, $p = .03$, $\eta^2_p = 0.11$) suggesting the presence of a horizontal STEARC effect. For both latencies and errors, results showed an association between the past and left key and the future and the right key, confirming a left-to-right MTL orientation. On the other hand, the Temporal Expression x Response Position ANOVA on RTs, considering only the vertical dimension, showed neither significant main effects nor significant interaction (all Fs < 0.69 with ps > .41 $\eta^2_{ps} < 0.02$). The same ANOVA on NEs revealed the same result (all Fs < 2.72 with ps > .11 $\eta^2_{ps} < 0.07$), suggesting the lack of a vertical STEARC effect, without an association between the past and the bottom keys and the future and the top keys. Thus, the obtained results could suggest a preference for the horizontal dimension than the vertical one.

Time-to-Position task. As shown in Figure 3a, Italian speakers placed the 20 temporal expressions along the positive diagonal linear timeline, in an ordered pattern from the left side at the bottom to the right side at the top. Indeed, the results showed a clear diagonal time representation (linear fit model: $R^2 = 0.812$; SD = 0.09; $t(38) = 57.71$, $p < .001$). Similarly, in the negative diagonal, Italian speakers placed the 20 temporal expressions along the diagonal linear timeline, in an ordered pattern from the left side at the top to the right side at the bottom, showing a diagonal time representation (linear fit model: $R^2 = 0.805$; SD = 0.08; $t(38) = 61.46$, $p < .001$) (Figure 3b).

In order to investigate whether a difference between the two ordered patterns (for the positive and negative diagonals) existed, we performed a series of comparison between each temporal expressions positioned on the positive and negative diagonal lines, with the criterion set for statistical significance equal to $p < .0025$, due to multiple comparisons. Results showed that all comparisons were not significant, suggesting that there was no difference between the two positioning patterns (Appendix B in the OSM (at: https://osf.io/yx9aq/?view_only=166720a36d3940bf8563146020b8507a)). Consequently, we performed the regression analysis for an unified ordered pattern, showing a mental diagonal time representation (linear fit model: $R^2 = 0.806$; SD = 0.08; $t(77) = 83.40$, $p < .001$).

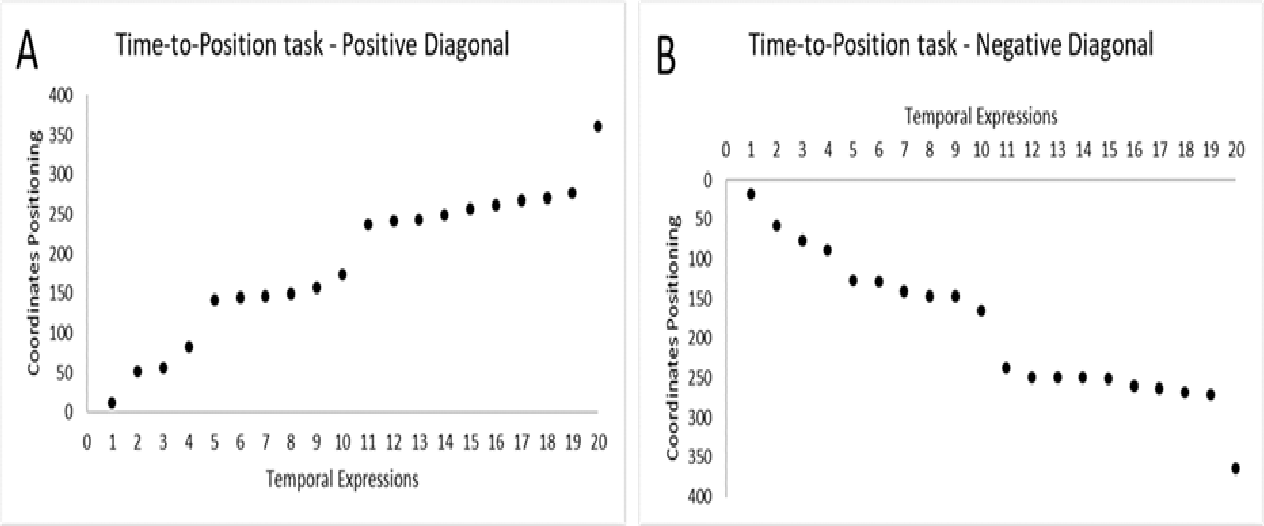

Figure 3. Distance of each temporal expression from the starting point of the diagonal line and subjective mark positioned with the cursor on the line, in the positive (Fig. 3a) and negative (Fig. 3b) diagonal of the Experiment 1.

The diagonal STEARC effect. In order to determine the direction and the strength of the space-time congruency effect, we performed the regression analysis described by Lorch and Myers (1990) calculating for each participant and each temporal expression, the average differences (dRT) between RTs for “U” and “C” keys (for the positive diagonal) and then, between RTs for “N” and “R” keys (for the negative diagonal). These differences were calculated and regressing these scores on superimposed temporal expression unified order (defined by the results of the Time-To-Position task). The slope coefficients were tested against zero by means of a one-tailed t-test.

Results showed that both the slope coefficients were significantly different from zero: positive diagonal (*b* = -11.86; SD = 25.04; *t*(38) = -2.76, *p*= .009) and negative diagonal (*b* = -13.11; SD = 31.46; *t*(38) = -2.60, *p*= .01) and there was no difference between them (*t*(38)= 0.24, *p*= .81), as shown in Figure 4.

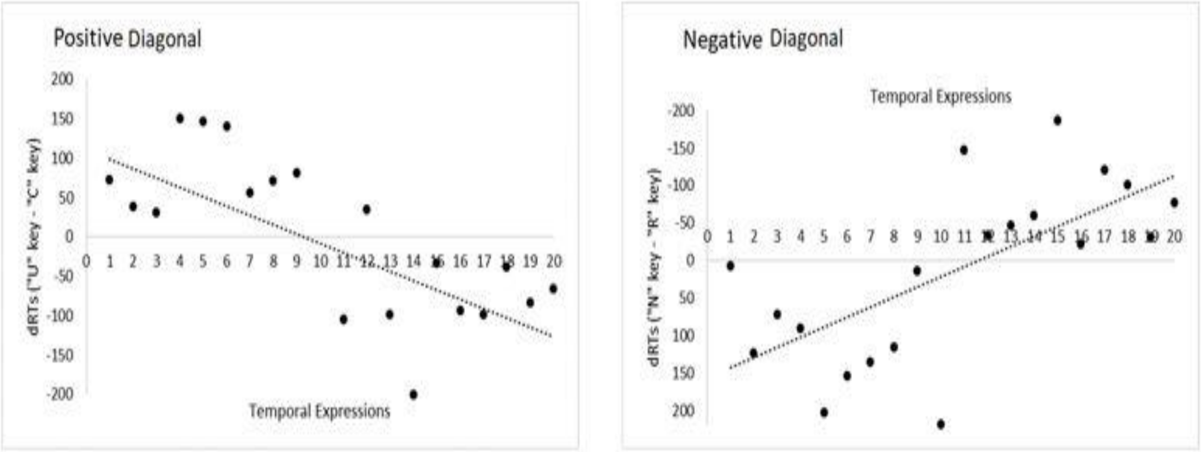

Figure 4. Mean differences between reaction times (dRTs; “U” key – “C” key for positive diagonal and “N” key – “R” key for negative diagonal) in Experiment 1, for each target expression (numbers 1 to 20) with the specific unified order sequence found in the Time-to-Position task.

Discussion

In an attempt to investigate the existence of a spatial-temporal association along the diagonals, our results showed a time representation along the positive and negative diagonals, with the past at the left- bottom corner and the future at the right-top corner along the positive diagonal, whereas the past was associated with the left- top space and the future was associated with the right- bottom space along the negative diagonal. Contrarily from our expectation (i.e., to expect a significant STEARC effect along the positive diagonal only), we showed a STEARC effect in both diagonals, and the slope coefficients of space-time congruency effect for both diagonals were similar due to the lack of significant difference between the two *b* values. However, the additional ANOVAs performed separately for the horizontal and vertical dimensions could reflect a dominance of the horizontal axis on the vertical one, in line with Gu and Zhang (2012). Therefore, our data could indicate that the horizontal information (left vs. right key) was the dominant information along both diagonals (Gu & Zhang, 2012), or at least the first spatial information which interacted with temporal processing. When the vertical space was considered, the direction of temporal representation along the positive diagonal derived from the congruency between past-future and left-right as well as bottom-up spaces for horizontal and vertical orientations respectively. This finding challenged that reported by Topić et al., (2021), who did not find a significant positive diagonal even if they considered the opposite direction for vertical dimension and no horizontal STEARC effect was found. As regards the negative diagonal, our data seemed to confirm previous findings in which the temporal information was represented along the left-top and right-bottom mental timeline, as our daily reading experience (from the left-top side of the page to the right-bottom; Pitt & Casasanto, 2020). Altogether our results could indicate a flexibility of vertical information, suggesting either the influence of gravity (Topić et al., 2021), or the evidence of our daily experience of verticality as floors in a building (Beracci et al., 2022). This flexibility could explain why we did not observe a Temporal Expression x Response Position interaction along the vertical dimension.

The result pattern reported in the speeded bimanual response task was further demonstrated in the free Time-to-Position task. In fact, our participants positioned the temporal expressions along the two diagonal lines (positive and negative), suggesting an ordered linear pattern along the diagonal axes. Although the results could resemble more a product of the experimental manipulation because participants had to position the expressions along a diagonal line presented on the screen, they placed each temporal expression (which did not involve a quantity and/or duration information) on a specific point of the line presenting an ordered pattern of the stimuli, suggesting that each target temporal expression was usually used to refer to specific time period by participants. In our opinion, these findings seemed to give additional evidence for the presence of a diagonal mental time representation (or for a mental travel along diagonals for referring to different temporal expressions). This result confirmed and extended along the diagonal dimension the results found by Beracci, Santiago et al. (2022) and Beracci and Fabbri (2022), regarding the horizontal and the vertical dimension. This finding could also be explained with the presence of a "*Spatial-Positional Association of Response Codes*" or SPoARC-like effect (Ginsburg et al., 2014) intended as the influence of a spatialization of the abstract concepts, that did not involve an information of quantity (as for the numbers or for the temporal durations) but they referred to different periods in the time. For example, the stimulus "*anticamente*" (in English: "*formerly*") could be positioned before "*recentemente"* (in English: "*recently*"), because the former expression refers to a remote past while the latter expression refers to a closer past. More important, we found that the displacement of temporal expressions along both diagonal lines was similar and thus we had the opportunity to create an "unique" diagonal line. Taking into account the ordered pattern of the same stimuli along horizontal and vertical spaces, it is possible to speculate that the mental timeline is oriented in different spaces according to the spatial information provided by the task setting.

In this Experiment 1, we found a STEARC effect along positive and negative diagonals, contrarily to our initial predictions. Thus, in a successive experiment, we expected to replicate this result pattern, presenting stimuli in each of four corners defining the diagonals. This procedure should resemble in more similar way the search array-procedure provided by Topić et al. (2021) in their go/no-go task. In addition, this experimental manipulation could test in a better way the influence of horizontal and vertical information on diagonal time representation and how the unexpected result of the first Experiment could be due to the flexibility of the vertical dimension.

Experiment 2

As shown in the previous experiment, we found a diagonal STEARC effect in which the diagonal information was provided by the spatial arrangements of response keys in both positive and negative diagonals. However, the diagonal information could be provided by the visual arrangements of stimuli given that it has been demonstrated a congruence between the stimuli location (e.g., left and right position on the screen) and the left-past and right-future spatial-temporal mapping as suggested by Santiago et al. (2007) for the horizontal space (see also Di Bono et al., 2012 with an implicit task). Thus, we investigated the influence of the visuo-spatial processing stage in this spatial-temporal association (Fabbri et al., 2013a, 2013b) with a probable increasing the saliency of the space-time congruency effect along the diagonal axis. In similar way to the procedure adopted by Sun et al. (2023) the visual presentation of temporal stimuli displayed along both diagonal spaces could increase the salience of the diagonal time representation.

The aim of the present experiment was to replicate the unexpected previous results with the additional spatial information provided by the spatial position of temporal stimuli on the screen, in line with the study by Santiago et al. (2007). The Experiment 2 was the same of the Experiment 1 in apparatus, stimuli, procedure, and response mode, with the only exception of the stimuli displacement on four corners of the screen (left-top, right-top, right-bottom and left-bottom). According to the results found in the Experiment 1, we expected to find both positive and negative diagonal STEARC effects, increasing the salience of diagonal information.

Participants

A new group of 38 Italian students (31 females; mean age = 25.89 ± 6.34 years) participated in an online study[2], in exchange for course credits. As for the first experiment, we based on a power analysis performed by Beracci and Fabbri (2022) with G*Power 3.1 (Erdfelder et al., 1996) on data from a meta-analysis on the space-time congruency effect (von Sobbe et al., 2019). Indeed, with an $a = .05$ and power = .80, the projected sample size needed with an effect size of .46 was approximately N = 12 for the within-group comparison, keeping Type I error at the desired level of 5%, with a high statistical power (80%). At the same time for this study, we applied the same decisions adopted in the Experiment 1 for the sample size. Participants filled in the Edinburgh Handedness Inventory (EHI; Oldfield, 1971) and based on the EHI scores, 37 participants were right-handed (M = 79.40; SD = 35.81) and 1 was left-handed (M = -88.89). Data from 1 participant (a male) were not included because we considered as exclusion criteria of outliers a maximum acceptable percentage of errors of 20% (see Grasso et al., 2022 for similar exclusion criteria of outliers). Thus, the data for the remaining 37 participants (31 females; mean age = 25.92 years; SD = 6.43 years; 36 right-handed) were analyzed. All participants had normal or corrected-to-normal vision and were not informed to the purpose of the study. Informed consent was obtained from all individual participants included and the study was approved by the Ethical Committee of the Department of Psychology at the University of Campania "Luigi Vanvitelli".

Stimuli and Procedure

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[2] This experiment was performed online due to the worldwide health emergency caused by the COVID-19 and the home confinement imposed by Italian government.

The stimuli and the procedure were the same as Experiment 1 with the only exception that stimuli were presented in four different positions of the screen: on the left-top (Figure 5a), on the right-top (Figure 5b), on the right-bottom (Figure 5c) on the left-bottom sides (Figure 5d). After the temporal judgement task, participants performed the positive and the negative version of the online Time-to-Position task (using the E-Prime 3.0), as for the Experiment 1.

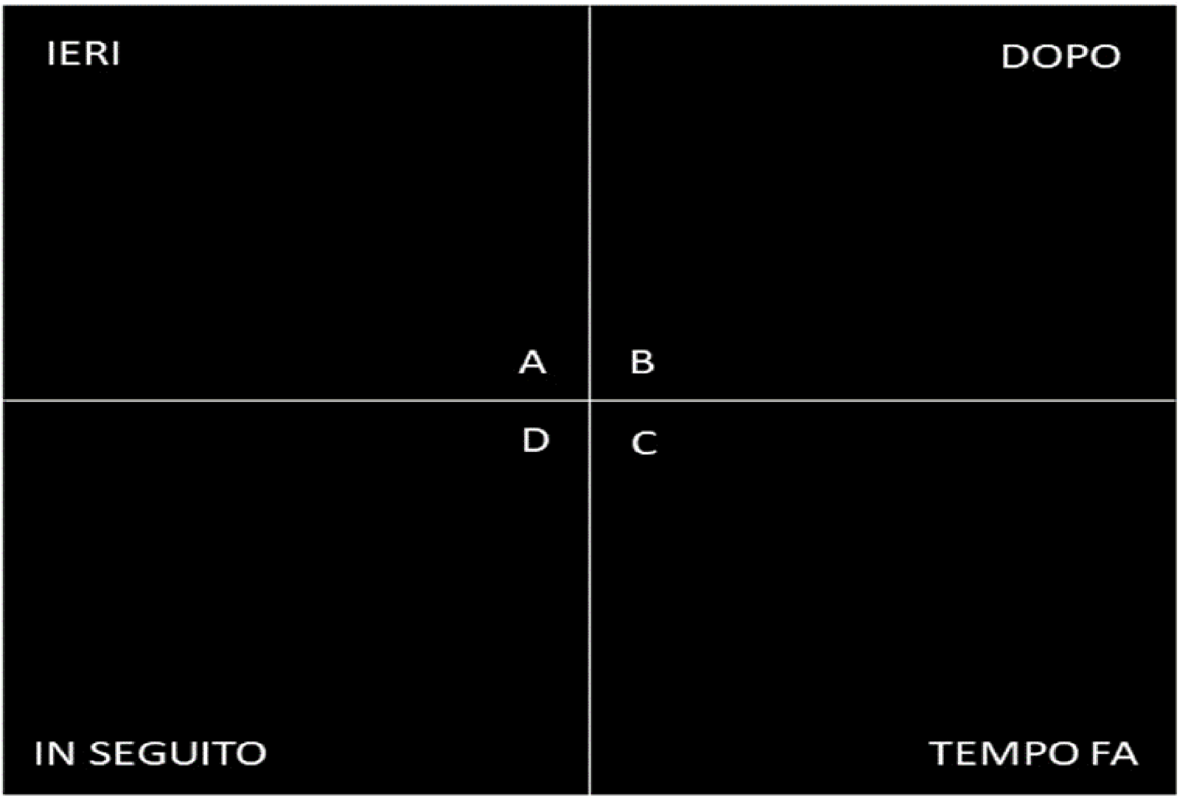


Figure 5. Example of stimuli presentation of temporal judgement task in the Experiment 2. In the first position, stimuli were located on the left at the top (Fig. 5a); in the second position, stimuli were located on the right at the top (Fig. 5b); in the third position, stimuli were positioned on the right at the bottom (Fig. 5c) and, in the fourth position, stimuli were positioned on the left at the bottom (Fig. 5d).

Data Analysis

Temporal judgement task

The mean RTs of correct responses were calculated using the software SPSS version 20.0 (IBM Corp.) To improve the internal validity of the study, RTs, that were more than 3 SDs above or below the mean, were discarded as outliers (about 1%). First of all, a three-way repeated measures ANOVA was carried out on RTs and accuracy (defined as number of errors (Nes)), with Temporal Expression (past vs. future), Response Position ("C" vs. "U" or "R" vs. "N) and Stimulus Location (1= top-left, 2= top-right, 3= bottom-right and 4= bottom-left) as within-subjects factors, in both positive and negative diagonals. Successively, two three-way repeated measures ANOVAs were carried out on RTs and NEs with Temporal Expression (past vs. future), Response Position ("C_R" as left vs. "N_U" as right keys and "C_N" as bottom and "R_U" as top keys) and Stimulus Location (1= top-left, 2= top-right, 3= bottom-right and 4= bottom-left) as within-subjects factors, merging all the data, in order to compare both diagonals and investigate the influence of horizontal and vertical information on the diagonal STEARC effect. When a reliable significance was found, the Bonferroni post-hoc test was run. The criterion set for statistical significance was $p < .05$ and we report the effect size (as eta partial square $\eta^2{}_p$).

Time-to-Position task

As for the previous Experiment, firstly we identified the starting point of the diagonal line in correspondence of the label "distant past" and then, we measured the distance from the starting point (for the positive condition: X= 352, Y= 512; for the negative condition: X= 338; Y= 262) of the line to the subjective mark positioned on the line with the cursor (i.e., Euclidean distance), for each participant and for each temporal expression. A linear fit model was tested for describing the positions of each temporal expression along the diagonal lines.

Results

Temporal judgement task. All descriptive data for RTs and accuracy (with their relative standard deviations or SDs) are displayed in Table 2.

For the positive diagonal, the Temporal Expression x Response Position x Stimulus Location ANOVA on RTs revealed the significant Temporal Expression x Response Position interaction ($F(1,36) = 21.65$, $p < .001$, $\eta^2_p = 0.38$) with faster responses for the past with the "C" key (M = 1142 ms; SD = 270 ms) than with the "U" key (M = 1293 ms; SD = 344 ms; $p < .001$) and for the future with the "U" key (M = 1152 ms; SD = 288 ms) than with the "C" key (M = 1351 ms; SD = 441; $p < .001$), as showed in Figure 6a (see Table C1 in Appendix C in the OSM (at: https://osf.io/yx9aq/?view_only=166720a36d3940bf8563146020b8507a) for the same results obtained by LMMs). Also, the analysis revealed a significant Response Position x Stimulus Location interaction ($F(3,36) = 3.70$, $p = .01$, $\eta^2_p = 0.09$) with faster responses with the "U" key for stimuli located on the second position (M = 1151 ms; SD = 275 ms) than on the first (M = 1247 ms; SD = 457 ms; $p < .001$), on the third (M = 1246 ms; SD = 327 ms; $p < .001$) or on the fourth position on the screen (M = 1247 ms; SD = 362 ms; $p = .004$). Moreover, the post-hoc did not reveal any significant comparison, even if results showed faster responses on the fourth position with the "C" key (M = 1212 ms; SD = 334 ms) than with stimuli positioned on the first (M = 1227 ms; SD = 387 ms; $p = .70$), on the second position on the screen (M = 1247 ms; SD = 320 ms; $p = .29$) or on the third position of the screen (M = 1260 ms; SD = 354; $p = .12$). Results revealed neither significant main effects nor other significant interactions (all $Fs < 1.83$ with $ps > .15$, $\eta^2_{ps} < 0.05$). The same ANOVA on NEs revealed neither significant main effects nor significant interactions (all $Fs < 2.46$ with $ps > .12$, $\eta^2_{ps} < 0.06$) (for the Temporal Expression x Response Position interaction see Figure 6c).

For the negative diagonal, the Temporal Expression x Response Position x Stimulus Location ANOVA on RTs revealed neither significant main effects nor significant interactions (all Fs < 3.53 with ps $> .07$, $\eta^2_{ps} < 0.09$). The Figure 6b displayed the no significant Temporal

Expression x Response Position interaction (see Table C2 in Appendix C in OSM (at: https://osf.io/yx9aq/?view_only=166720a36d3940bf8563146020b8507a) for the same results obtained by LMMs). The same ANOVA on NEs showed the significant main effect for Stimulus Location ($F(3,36) = 2.84$, $p < .05$, $\eta^2_p = 0.07$) and the significant Temporal Expression x Response Position interaction ($F(1,36) = 5.25$, $p = .03$, $\eta^2_p = 0.13$). For the significant main effect, the post hoc did not reveal any significant comparison (with the criterion set for statistical significance equal to $p < .008$) even if there were less errors for stimuli located on the first position (M = 3.38; SD = 5.74) than on the second (M = 5.07; SD= 8.87; $p = .06$), the third (M= 4.53; SD = 8.10; $p = .03$) or the fourth position of the screen (M = 5.07; SD = 7.02; $p = .03$). Additionally, participants performed less errors for the stimuli located on the third position (M= 4.53; SD = 8.10) than on the second (M = 5.07; SD= 8.87; $p = .93$) or on the fourth (M = 5.07; SD = 7.02; $p = .75$), but there was no difference between the stimuli positioned on the second (M = 5.07; SD= 8.87) and on the fourth position (M = 5.07; SD = 7.02; $p = .82$). As regards the Temporal Expression x Response Position interaction, the post-hoc test did not reveal any significant comparison even there were less errors for the past with the “R” key (M = 2.90; SD = 5.03) than with the “N” key (M = 4.80; SD = 9.39; $p = .12$) and for the future with the “N” key (M = 4.12; SD = 6.57) than with the “R” key (M = 6.22; SD = 8.74; $p = .06$), as shown in Figure 6d.

Given the contradictory results obtained, with a significant space-time association only for the positive diagonal and not for the negative one, we performed an additional three-way ANOVA on RTs with Diagonal (Positive vs. Negative), Response-Stimuli Position Congruency (Congruent vs. Incongruent) and Time (Past vs. Future) as within-subjects factors, in order to show a reliably difference between the two diagonals. Results showed a significant triple interaction, $F(1,36) = 4.56$, $p = .04$, $\eta^2_p = .11$, disentangling the doubts regarding the lack of a systematic significant STEARC effect in both diagonals.

Table 2. Reaction times (RTs) in ms and number of errors (NEs) (SDs in brackets) respectively for past and future temporal expressions positioned in different locations of the screen and judged with the “C” or “U” key, in the positive diagonal and, with the “R” or “N” key, in the negative diagonal, in the Experiment 2.

Positive Diagonal

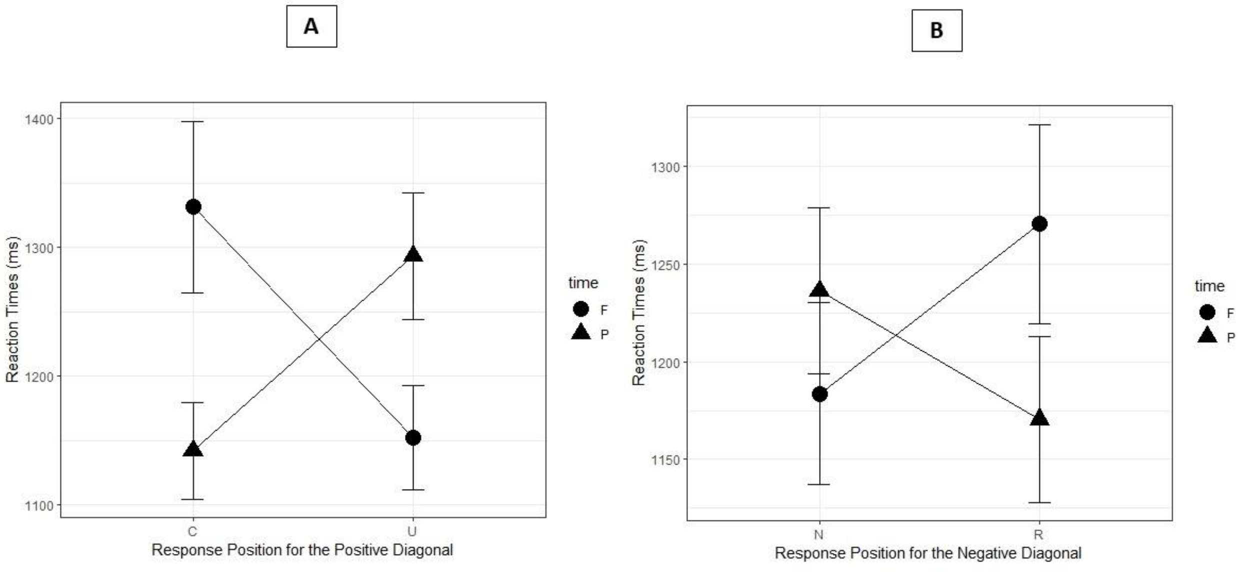
Response Position	**Stimuli Position**	**Temporal Expression**			
		PAST		**FUTURE**	
		RTs	**NEs**	**RTs**	**NEs**
“C” KEY	**TOP-LEFT**	1098 ms (260 ms)	3.51 (6.33)	1357 ms (514 ms)	5.41 (8.36)
	TOP-RIGHT	1200 ms (316 ms)	3.24 (5.80)	1294 ms (375 ms)	6.76 (13.55)
	BOTTOM-RIGHT	1145 ms (251 ms)	2.97 (5.71)	1375 ms (457 ms)	7.03 (11.75)
	BOTTOM-LEFT	1125 ms (252 ms)	4.05 (5.99)	1299 ms (417 ms)	5.41 (11.45)
	TOP-LEFT	1313 ms (317 ms)	3.78 (7.58)	1181 ms (280 ms)	5.14 (6.51)
	TOP-RIGHT	1218 ms (280 ms)	5.14 (9.32)	1083 ms (271 ms)	4.05 (6.85)

“U” KEY					
	BOTTOM-RIGHT	1304 ms (381 ms)	4.32 (5.55)	1188 ms (273 ms)	8.38 (9.28)
	BOTTOM-LEFT	1337 ms (398 ms)	4.59 (6.91)	1156 ms (327 ms)	5.14 (7.68)

Negative Diagonal

Response Position	**Stimuli Position**	**Temporal Expression**			
		PAST		**FUTURE**	
		RTs	**NEs**	**RTs**	**NEs**
“R” KEY	**TOP-LEFT**	1177 ms (302 ms)	1.62 (3.74)	1290 ms (387 ms)	3.78 (6.39)
	TOP-RIGHT	1158 ms (306 ms)	3.78 (5.94)	1302 ms (362 ms)	5.95 (9.56)
	BOTTOM-RIGHT	1155 ms (267 ms)	2.97 (4.63)	1252 ms (356 ms)	6.22 (8.28)
	BOTTOM-LEFT	1191 ms (315 ms)	3.24 (5.80)	1238 ms (342 ms)	8.92 (10.74)
		1258 ms	3.78	1199 ms	4.32

“N” KEY	**TOP-LEFT**	(283 ms)	(5.94)	(325 ms)	(6.89)
	TOP-RIGHT	1224 ms (319 ms)	6.22 (12.33)	1130 ms (267 ms)	4.32 (7.65)
	BOTTOM-RIGHT	1253 ms (282 ms)	4.59 (12.60)	1245 ms (388 ms)	4.32 (6.89)
	BOTTOM-LEFT	1210 ms (317 ms)	4.59 (8.69)	1161 ms (270 ms)	3.51 (4.84)



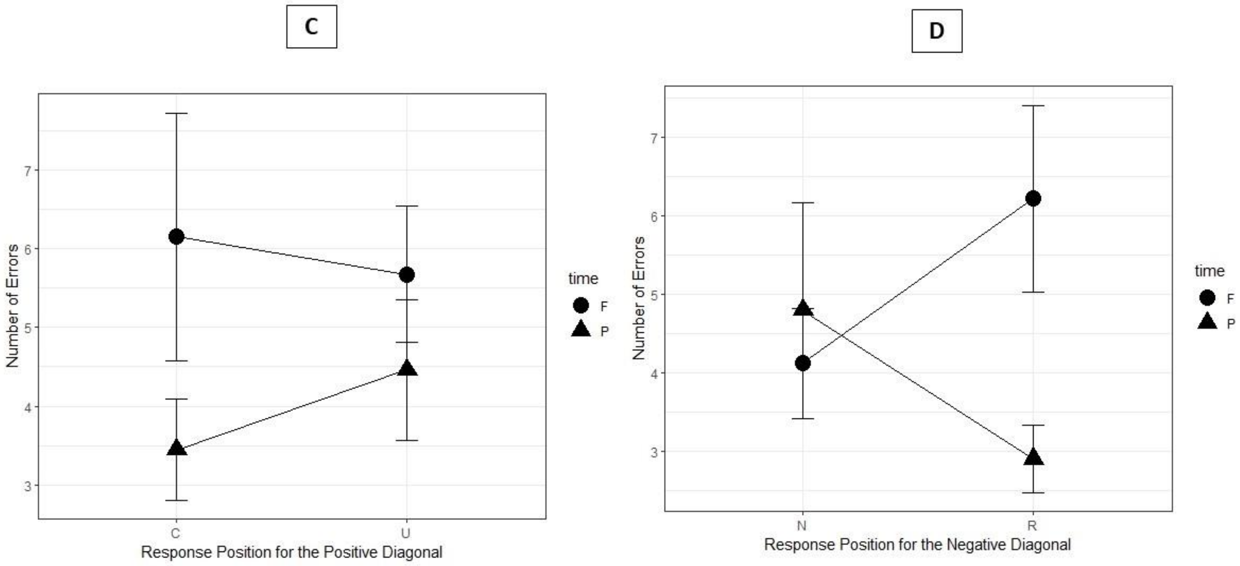


Figure 6. Mean Reaction Times (RTs in ms) and number of errors (NEs), with the bars representing their SEs, for “C” and “U” keys (Fig. 6a for RTs and Fig. 6c for Nes) and for “R” and “N” keys (Fig. 6b for RTs and Fig. 6d for Nes) when judging past and future target expression in Experiment 2.

Subsequently, the Temporal Expression x Response Position x Stimulus Location ANOVA considering only the horizontal dimension, revealed a significant Temporal Expression x Response Position interaction for the RTs ($F(1,37) = 16.82$, $p < .001$, $\eta^2_p = 0.31$) and NEs ($F(1,36) = 4.76$, $p = .04$, $\eta^2_p = 0.12$), suggesting a probable preference for the horizontal than for the vertical dimension. This conclusion was supported also from the results obtained by the Temporal Expression x Response Position x Stimulus Location ANOVA considering only the vertical dimension which revealed neither significant main effects nor a significant interaction on RTs (all $Fs < 3.99$ with $ps > .053$, $\eta^2_{ps} < 0.10$) and NEs (all $Fs < 2.51$ with $ps > .09$, $\eta^2_{ps} < 0.06$).

Time-to-Position task results. As shown in Figure 7a, Italian speakers placed the 20 temporal expressions along the positive diagonal linear timeline, in an ordered pattern from the left-bottom-to- right-top. Indeed, the results showed a clear diagonal time representation (linear fit model: R^2= 0.805; SD = 0.07; $t(36) = 67.94$, $p < .001$). Similarly, in the negative diagonal, Italian speakers placed the 20 temporal expressions along the diagonal linear timeline, in an ordered pattern from the left side at the top to the right side at the bottom, showing a diagonal time representation (linear fit model: $R^2 = 0.810$; SD = 0.08; $t(36) = 61.65$, $p < .001$) (see Figure 7b).

As for the previous Experiment, we performed a series of comparison between each temporal expressions positioned on the positive and negative diagonal line, with the criterion set for statistical significance equal to $p < .0025$. Results showed that all comparisons were not significant, suggesting that there was no difference between the two positioning patterns (see Appendix D in the OSM (at: https://osf.io/yx9aq/?view_only=166720a36d3940bf8563146020b8507a)). Consequently, we performed the regression analysis for an unified ordered pattern, showing a mental diagonal time representation (linear fit model: $R^2 = 0.789$; SD = 0.09; $t(73) = 75.65$, $p < .001$).

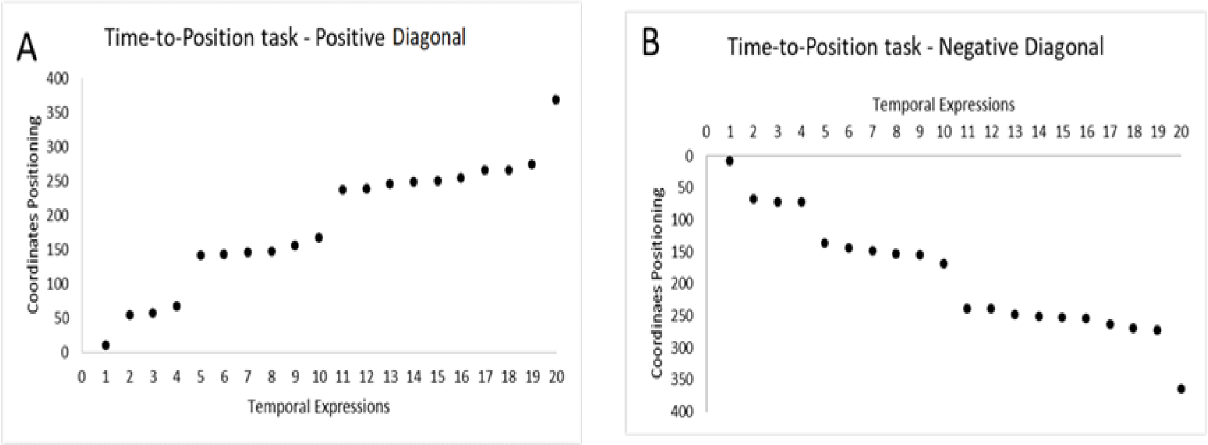


Figure 7. Distance of each temporal expression from the starting point of the diagonal line and subjective mark positioned with the cursor on the line, in the positive (Fig. 7a) and negative (Fig. 7b) diagonal of the Experiment 2.

The diagonal STEARC effect. As for the previous Experiment, we analysed the STEARC effect (see Dehaene et al., 1993, for the SNARC effect) to determine the direction and the strength of the space-time congruency effect, performing the same regression analysis described in the Experiment 1 (Lorch & Myers, 1990). The results showed that slope coefficients was significantly different from zero only for the positive diagonal (*b* = -20.53; SD = 32.62; *t*(36) = -3.83, *p* < .001) but not for the negative diagonal (*b* = -9.52; SD = 37.36; *t*(36) = -1.55,*p* = .13) and there was no difference between them (*t*(36) = -1.65, *p* = .11), as shown in the Figure 8.

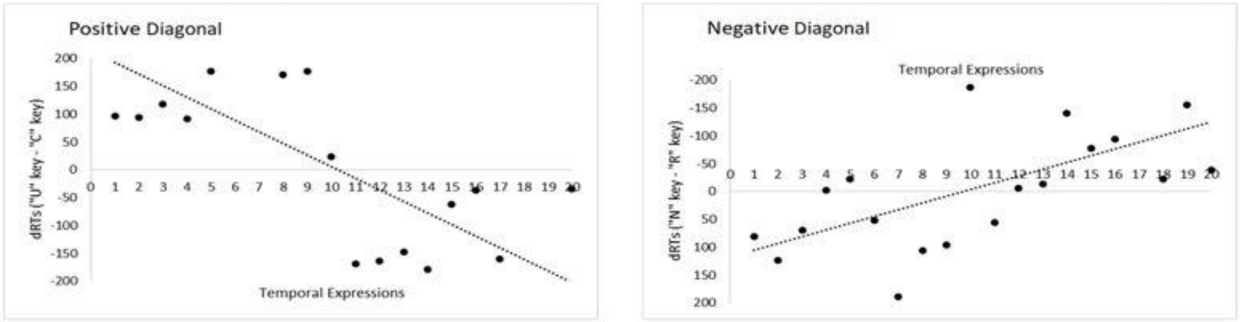


Figure 8. Mean difference between reaction times (dRTs) ("U" key – "C" key for positive diagonal and "N" key – "R" key for negative diagonal) in Experiment 2, for each target expression (numbers 1 to 20) with the specific unified order sequence found in the Time-to-Position task.

Discussion

In this second Experiment, we added spatial information presenting the temporal stimuli in every four corners of the space, trying to replicate the results obtained in Experiment 1 and to increase the saliency of the congruency effect found in the previous Experiment for both diagonals. In this case, we confirmed the positive diagonal while the analysis performed along the negative diagonal did not reveal any significant interaction. Thus, we could conclude the presence of a STEARC effect with an association between the past and the left-bottom key and the future and the right-top key, typically preferred for Western individuals (Sun et al., 2023).

In addition, we found that the slope coefficient for the positive diagonal was significantly differed from zero whereas the *b* value of the negative diagonal did not. The difference between diagonals in the interaction between Response Position and Temporal Expression could suggest that the spatial-temporal associations in the positive diagonal could derive from the combination of the left-to-right direction (the dominant dimension, see below for a discussion) horizontally and of the bottom-to-top direction vertically (Sun et al., 2023). In other words, when the vertical information was processed, this information did not contrast the "suggested direction" of the horizontal line, but it integrated the time representation determining a diagonal orientation in which vertical information was "congruent" with typical vertical experience in the real life. The combination of horizontal and vertical information along the positive diagonal could be also supported by a Simon-like effect found in the study with a preference to press "C" (i.e., left-bottom) and "U" (i.e., right-top) buttons when temporal stimuli appeared in the same spatial position. The significant STEARC effect along the positive diagonal and no STEARC effect (either with RTs or regression analyses) along the negative diagonal, indicated that the vertical representation of time was mainly based on a bottom-to-top orientation of timeline, according to the "more-is-up" metaphor, respect to a top-to-down direction of MTL, in line with the "gravity" account. In other words, this was additional evidence that the bottom-to-top direction of MTL (Beracci, Rescott et al., 2021) was preferred respect to the top-to-bottom direction (Topić et al., 2021). The discrepant results found in the speeded binary task between the Experiment 1 and Experiment 2 could be related to the spatial position of the temporal stimuli, which were centrally presented in the first experiment whereas they were spatially located in the second one. The spatial position of the stimuli could be a sufficient reason for weakening the STEARC effect along the negative diagonal. For example, Sun et al. (2023) found a preference for the positive diagonal in English participants in similar way to our Italian participants.

However, the comparison between both *b* values was not significant and thus the two coefficients could not be treated as different, (see Nieuwenhuis et al., 2011). In line with this assumption, we confirmed the presence of an ordered linear pattern of the 20 temporal expressions in both positive and negative diagonals in the Time-to-Position task. As for the previous Experiment, a SPoARC-like effect in our Time-To-Position task would indicate not only that the STEARC effect arises from the associations between past/future and spatial positions of response keys but also it suggests the involvement of a spatialization of temporal expressions along a diagonal line that represented different temporal frames. However, it remains to understand how much the request to place temporal expressions along a “physical” line could explain our data. The fact that, in two different diagonal lines, participants placed in similar way and with the same order the temporal expressions, could rule out the task constrains (e.g., a diagonal line with two flankers) in the performance.

In addition, we found that the horizontal dimension was mainly responsible for the STEARC effect along both diagonals, confirming the unexpected results obtained in the first experiment. As before the weak (or even the absence) contribution of the vertical dimension could be related to the possibility to think time along a top-to-bottom as well as along a bottom-to-top direction vertically. In an attempt to “recreate” a search array, the present experiment, in addition with what has been already showed in the first experiment, could questioned the findings provided by Topić et al. (2021), who found that the diagonal information derived from vertical information only. At the same time, the different task request between the study by Topić et al. (2021) and the present research could explain this different result pattern given that in the former study the temporal information was implicit for performing the task, whereas in the latter study the temporal information was explicitly processed for the task requirement.

General Discussion

The aim of this study was to investigate the mental time representation along the diagonal axes, from left-bottom-to-right-top and from left-top-to-right-bottom, motivated by the intention to discover whether humans being represent time in a mental map built through the space.

Participants performed the Experiment 1, in which they had to judge 20 temporal expressions as past or future, presented always centrally on the screen, with two pairs of response buttons of a standard keyboard: the “C” and “U” keys for the positive diagonal and the “R” and “N” keys for the negative diagonal. Successively, in the Experiment 2 participants performed the same temporal judgement task with the only exception that stimuli were displaced in different positions of the screen in order to increase the saliency of both diagonal dimensions (Santiago, et al., 2007; Santiago et al., 2010). On the whole, we obtained probable evidence regarding the time representation along the positive diagonal (Hartmann et al., 2014) because in both experiments, we found spatial-temporal associations between past and left-bottom space as well as future and right-top space. As regards the positive (from left-bottom to right-top) diagonal, our data were in contrast with that obtained in the first diagonal by Topić et al. (2021), but in line with those reported by Sun et al. (2023) for Western participants. Indeed, the authors did not find a significant spatial-temporal association between the past and the left-bottom space and the future and the right-top space, contrarily to our results. A possible reason for this result pattern could be related to the fact that previous evidence showed significant horizontal and vertical time representations and these both cardinal axes influenced the way we could represented time along diagonals. Beyond the well-documented interaction of the horizontal (left-right) space with time processing (Bonato et al., 2012; Di Bono et al., 2012; Ouellet et al., 2010; Santiago et al., 2007; Torralbo et al., 2006; Weger & Pratt, 2008), at least in Western culture, a brief review of the spatial-temporal association along the vertical dimension revealed that the majority of studies suggested that past was associated with the bottom space whereas future was associated with the top space (Beracci, Rescott et al., 2021; Beracci & Fabbri, 2022; Dalmaso et al., 2022; Leone et al., 2018;Ruiz Fernández et al., 2014). Thus, for instance, the “C” key contained both horizontal (left space) and vertical (bottom space) information, defining a “congruent” situation when this key had to be pressed for judging past expression respect to other keys (see Gevers et al., 2006 for similar consideration with numbers). An additional reason for the contrasting results between the present study and that performed by Topić et al. (2021) was related to the type of task performed by participants. In our study, participants coded two spatialized response buttons (with horizontal and vertical information contemporarily available) whereas in Topić et al.’ study participants pressed a central button, and the spatial information was provided by the spatial position of target in the grid.

However, we did not show conclusive results regarding the negative diagonal (from left-top to right-bottom) because we found a significant STEARC effect in the Experiment 1 only. Although the results in the Experiment 1 seemed to confirm the possibility that the temporal information was represented along this negative diagonal and we could not exclude the influence of gravity (Topić et al., 2021), or the experience of our daily reading experience (from the left-top side of the page to the right-bottom; Pitt & Casasanto, 2020) in representing time, we posited the main idea that significant result found in the Experiment 1 derived probably by the influence of the spatial-temporal interaction along the horizontal axis. Given that participants had to press “R” or “N” keys, they probably coded more the horizontal displacement of the keys (“R” was on left and “N” was on right) than the contemporary vertical information (“R” was on the top and “N” was on bottom). This assumption was also based on the fact that the spatial information in the Experiment 1 was only provided by the spatial arrangements of the keys along the keyboard. Related to this point, the lack (or at least the weakness) of the STEARC effect in the Experiment 2 for negative diagonal could depend on the displacement of the temporal stimuli in all four corners of the screen and thus the negative diagonal information was provided by both spatial keys and spatial position of the stimuli. This additive spatial information could mask the STEARC effect on RTs for negative diagonal. Although we did not observe significant post-hoc comparisons, we found a STEARC effect along the negative diagonal when NEs were analyzed, suggesting that this effect seemed to arise in later stage of the spatial-temporal processing. In line with this consideration, as Fabbri et al. (2013a, 2013b) suggested for horizontal space, the superiority of motor component (response selection) could mask the spatial information provided by perceptual component (intended as the visuo-spatial processing stage) in the mental representation of time (see Gevers et al., 2006 for a similar account with numbers). Therefore, we could assume the stronger influence of the execution stage, represented by the response selection, rather than the influence of the perceptual manipulation as the spatial attention to the stimuli displacement (Fabbri et al., 2013a, 2013b). Contrarily to Santiago et al., (2011), the motor activation, using the response keys, had a presumably stronger efficacy than the spatial attention involved to the stimuli displacement recognition and, consequently, the diagonal space-time association found seemed to be mainly related to the response mapping rather than the stimuli location (see also Beracci, Rescott et al., 2021 with temporal durations along the vertical dimension). Further studies should manipulate the spatial information provided by the response keys and/or by temporal stimuli for addressing the impact motor and visuo-spatial processing in the spatial-temporal associations in different spaces.

In line with the findings provided by Gu and Zhang (2012), in both experiments we found that the horizontal information was the relevant axis for determining the STEARC effects found along the diagonals respect to the vertical information. As reported by Gu and Zhang (2012), the horizontal space was stronger than the vertical one given that we made daily experience of horizontal dimension. Indeed, since early childhood and particularly in school age, we have experienced the horizontal dimension through the learning of writing or measurement (e.g., the use of the ruler) with a direction that goes from left to right. This kind of learning has established a superiority of the horizontal dimension that has become direct, consolidating over time (Sun et al., 2023). Then, we have to learn the distinction between left and right, through different types of strategies (or games), in the early years of the life of children. In addition to the dominance of the horizontal space, in the literature there are unconclusive results about the directionality of the time representation vertically. Indeed, we could have experience that time “falls” down from top-to-bottom according to the law of the gravity (Topić et al., 2021) or that time “goes up” from bottom-to-top, as an elevator from the ground floor to the attic, in line with the “more-is-up” metaphor (Beracci, Rescott, et al., 2021; Beracci, Santiago, et al., 2022; Beracci & Fabbri, 2022; Lakoff & Johnson, Mark, 1980). This flexibility of the time representation along the vertical axis could also confirm the superiority of the horizontal information for the time mapping along both diagonals. Although it is speculative, the fact that in the Experiment 2 (i.e., when we added a further spatial information, such as the spatial position of the stimuli on the screen) we found a STEARC effect for the positive diagonal only could indicate that the spatial manipulation of temporal stimuli could “increase” the “habitual” vertical experience of time processing (Hartmann et al., 2014), that is a bottom-to-top MTL, according to the metaphor of the “more-is-up” (Beracci, Rescott, et al., 2021; Beracci, Santiago, et al., 2022; Beracci & Fabbri, 2022; Lakoff & Johnson, Mark, 1980), in line with the experience that we need time to reach the top of a mountain seemed to be “preferred” ways to represent the passage of time. Future studies should investigate the spatial representation of time in different cultures and in which way horizontal, vertical and diagonal spaces interact with each other and/or are influenced by cultural habits.

However, we found a spatial-temporal association along two diagonal axes (positive and negative), when participants were free to place different temporal stimuli along a diagonally-drawn line, in the Time-to-Position task. As explained in previous studies in which a similar procedure was used (see Beracci, Santiago et al., 2022 for the horizontal dimension and/or Beracci & Fabbri, 2022 for the vertical dimension), we chose to use a single diagonal line for each condition, in order to increase the possibility of adopting a diagonal dimension in representing time respect to, for instance, the use of an empty space (for this procedure see for e.g., Woodin & Winter, 2018). Although we could not completely rule out the influence of the use of flanked line in determining ordered displacement of temporal stimuli along both diagonals, our results seemed to indicate the presence of a SPoARC-like effect (Ginsburg et al., 2014; Zhou et al., 2019), not only confirming the findings of the temporal judgment task but also indicating that the temporal expressions could be ordered linearly along the diagonal spaces. In other words, we assumed that a contrasting orientation of temporal stimuli along both diagonals could be the result of a specific sequence of activation of spatial information. Indeed, in both diagonals, the horizontal information was firstly activated determining the starting point of sequence (i.e., from left-to-right). Then, the vertical information was processed and added to the sequence determining the top-to-bottom or bottom-to-top direction of the sequence, confirming the results obtained in the temporal judgement task. This assumption was grounded on the fact we observed a similar ordered sequence in both diagonal Time-to-Position tasks.

Limitations

It is worth noting an additional aspect regarding our consideration of the diagonal dimension as the combination of the horizontal and the vertical dimension. Although, investigating the vertical mental timeline Beracci and Fabbri (2022) showed that there were not a significant difference between the space-time association obtained using a response box positioned vertically (considered as “real” vertical dimension) and using the directional arrows of a standard keyboard (“down” and “up” arrows; considered as “analogous” vertical dimension), we could not avoid to underlie that our results could be interpreted as a spatial-temporal representation along the sagittal axis. Indeed, in our study, participants used two pairs of keys of a standard keyboard, and the vertical information could be masked by a sagittal (C-N were close to whereas R-U were far away from). Regarding this point, we could interpret our results according to two dominant spatial metaphors used to sequence events in time (Lakoff & Johnson, 1980; Boroditksy, 2000). The first was the *ego-moving metaphor*, in which the person's context progressed along the timeline towards the future and front was assigned to a future or later events. In this metaphor, the observer or the person moved along a path and objects were ordered according to the direction of the motion of the observer (e.g., "*we are coming up on summer*"). Then, the second metaphor was the *time-moving metaphor*, in which a timeline was conceived as a river on which events were moving from the future to the past, and front was assigned to a past or earlier events (e.g., "*summer is coming up*").

Although the sagittal perspective could be not completely excluded due to the spatial disposition of our response keys, in our opinion, the choice of R and N for negative diagonal and C and U for positive diagonal resembled the choice adopted in previous studies addressing diagonal representation for numbers (Gevers et al., 2006) and time (Gu & Zhang, 2012). In those studies, the negative diagonal was induced by numerical keys 7 and 3 of a standard numerical keypad whereas the positive diagonal was induced by numerical keys 1 and 3 of the same keypad. In our opinion the similarity between our alphabetic keys and previously used numerical keys could account for the data interpretation of the present research along a diagonal mapping. Considering that both experiments were performed during the first home confinement in Italy, the choices of our response keys was also based on the necessity to provide keys spatially located along both diagonals. Future studies are needed to replicate both experiments using a response box positioned both in a horizontal and in a (real) vertical orientation.

Conclusions

To sum up, participants performed a temporal judgement task with 20 temporal expressions referred to past and future, positioned always centrally (in the Experiment 1) or in different positions of the screen (in the Experiment 2), using a diagonal response arrangement, in order to investigate a mental time representation along the diagonal axis. Results showed a spatial-temporal association along the positive diagonal (from left-bottom to right-top) in both experiments, while space-time associations along the negative diagonal (from left-top to right-bottom) seemed to be influenced by task setting. However, our findings seemed to claim for a probable presence of a mental map of the time intended as a combination of the horizontal and vertical axis in the Cartesian plan. Indeed, we could assume that the horizonal information was firstly activated determining the starting point of the MTL that has a left-to-right direction, influenced by the learned network of associations, during the evolutionary process and, consolidated over the time (e.g., the writing or measurement process). Successively, there was the involvement of the vertical axis, added to the horizontal dimension, that was influenced by the daily experiences and was flexible (e.g., the law of gravity experience, from top-to-bottom or, the growth process from a child to an adult, from bottom-to-top). Future studies should investigate in a deeper way which is (if it exists) the dominant or preferred time representation along the vertical axis influencing the spatial-temporal interactions along both diagonal dimensions. In addition, subsequent studies should replicate the experimental procedure adopted in this research in a laboratory setting given that both experiments were performed during the first Italian COVID-19 lockdown and the online procedure did not guarantee the control level typically reached in a laboratory setting.

Declarations

Conflict of Interests The authors declare that they have no conflict of interest

Ethics Approval The manuscript does not contain clinical studies or patient data

Consent to Participate Informed consent was obtained from all individual participants included in the study

Consent for Publication Consent for publication was obtained by both the authors

References

Arzy, S., Adi-Japha, E., & Blanke, O. (2009). The mental time line: An analogue of the mental number line in the mapping of life events. *Consciousness and Cognition*, *18*(3), 781–785. https://doi.org/10.1016/j.concog.2009.05.007

Arzy, S., Collette, S., Ionta, S., Fornari, E., & Blanke, O. (2009). Subjective mental time: The functional architecture of projecting the self to past and future. *European Journal of Neuroscience*, *30*(10), 2009–2017. https://doi.org/10.1111/j.1460-9568.2009.06974.x

Beracci, A., & Fabbri, M. (2022). Past on the ground floor and future in the attic: The vertical mental timeline. *Journal of Experimental Psychology: Human Perception and Performance*, *48*(4), 380–399. https://doi.org/10.1037/xhp0000988

Beracci, A., Rescott, M. L., Natale, V., & Fabbri, M. (2021). The vertical space–time association. *Quarterly Journal of Experimental Psychology*, 174702182110570. https://doi.org/10.1177/17470218211057031

Beracci, A., Santiago, J., & Fabbri, M. (2022). The categorical use of a continuous time representation. *Psychological Research*, *86*(4), 1015–1028. https://doi.org/10.1007/s00426-021-01553-y

Bergen, B. K., & Chan Lau, T. T. (2012). Writing Direction Affects How People Map Space Onto Time. *Frontiers in Psychology*, *3*. https://doi.org/10.3389/fpsyg.2012.00109

Bonato, M., Zorzi, M., & Umiltà, C. (2012). When time is space: Evidence for a mental time line. *Neuroscience & Biobehavioral Reviews*, *36*(10), 2257–2273. https://doi.org/10.1016/j.neubiorev.2012.08.007

Boroditsky, L. (2000). Metaphoric structuring: Understanding time through spatial metaphors. *Cognition*, *75*(1), 1–28. https://doi.org/10.1016/S0010-0277(99)00073-6

Boroditsky, L. (2001). Does Language Shape Thought?: Mandarin and English Speakers' Conceptions of Time. *Cognitive Psychology*, *43*(1), 1–22. https://doi.org/10.1006/cogp.2001.0748

Boroditsky, L., Fuhrman, O., & McCormick, K. (2011). Do English and Mandarin speakers think about time differently? *Cognition*, *118*(1), 123–129. https://doi.org/10.1016/j.cognition.2010.09.010

Casasanto, D., & Jasmin, K. (2012). The Hands of Time: Temporal gestures in English speakers. *Cognitive Linguistics*, *23*(4). https://doi.org/10.1515/cog-2012-0020

Chen, J.-Y. (2007). Do Chinese and English speakers think about time differently? Failure of replicating Boroditsky (2001). *Cognition*, *104*(2), 427–436. https://doi.org/10.1016/j.cognition.2006.09.012

Dalmaso, M., Schnapper, Y., & Vicovaro, M. (2022). When time stands upright: STEARC effects along the vertical axis. *Psychological Research*. https://doi.org/10.1007/s00426-022-01693-9

Dehaene, S., Bossini, S., & Giraux, P. (1993). The Mental Representation of Parity and Number Magnitude. *Journal of Experimental Psychology*, *122*, 371–396. https://doi.org/10.1037//0096-3445.122.3.371

Di Bono, M. G., Casarotti, M., Priftis, K., Gava, L., Umiltà, C., & Zorzi, M. (2012). Priming the mental time line. *Journal of Experimental Psychology: Human Perception and Performance, 38*(4), 838–842. https://doi.org/10.1037/a0028346

Erdfelder, E., Faul, F., & Buchner, A. (1996). GPOWER: A general power analysis program. *Behavior Research Methods, Instruments, & Computers*, *28*(1), 1–11. https://doi.org/10.3758/BF03203630

Fabbri, M., Cellini, N., Martoni, M., Tonetti, L., & Natale, V. (2013a). Perceptual and motor congruency effects in time–space association. *Attention, Perception, & Psychophysics*, *75*(8), 1840–1851. https://doi.org/10.3758/s13414-013-0519-9

Fabbri, M., Cellini, N., Martoni, M., Tonetti, L., & Natale, V. (2013b). The Mechanisms of Space-Time Association: Comparing Motor and Perceptual Contributions in Time Reproduction. *Cognitive Science*, *37*(7), 1228–1250. https://doi.org/10.1111/cogs.12038

Fuhrman, O., & Boroditsky, L. (2010). Cross-Cultural Differences in Mental Representations of Time: Evidence From an Implicit Nonlinguistic Task. *Cognitive Science*, *34*(8), 1430–1451. https://doi.org/10.1111/j.1551-6709.2010.01105.x

Fuhrman, O., McCormick, K., Chen, E., Jiang, H., Shu, D., Mao, S., & Boroditsky, L. (2011). How Linguistic and Cultural Forces Shape Conceptions of Time: English and Mandarin Time in 3D. *Cognitive Science*, *35*(7), 1305–1328. https://doi.org/10.1111/j.1551-6709.2011.01193.x

Gevers, W., Lammertyn, J., Notebaert, W., Verguts, T., & Fias, W. (2006). Automatic response activation of implicit spatial information: Evidence from the SNARC effect. *Acta Psychologica*, *122*(3), 221–233. https://doi.org/10.1016/j.actpsy.2005.11.004

Ginsburg, V., van Dijck, J.-P., Previtali, P., Fias, W., & Gevers, W. (2014). The impact of verbal working memory on number–space associations. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *40*(4), 976–986. https://doi.org/10.1037/a0036378

Grasso, C. L., Ziegler, J. C., Mirault, J., Coull, J. T., & Montant, M. (2022). As time goes by: Space-time compatibility effects in word recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *48*(2), 304–319. https://doi.org/10.1037/xlm0001007

Gu, Y.-Y., & Zhang, Z.-J. (2012). The Horizontal and the Vertical Mental Timeline in Chinese Context: The Horizontal and the Vertical Mental Timeline in Chinese Context. *Acta Psychologica Sinica*, *44*(8), 1015–1024. https://doi.org/10.3724/SP.J.1041.2012.01015

Hartmann, M., Martarelli, C. S., Mast, F. W., & Stocker, K. (2014). Eye movements during mental time travel follow a diagonal line. *Consciousness and Cognition*, *30*, 201–209. https://doi.org/10.1016/j.concog.2014.09.007

Hartmann, M., & Mast, F. W. (2012). Moving along the mental time line influences the processing of future related words. *Consciousness and Cognition*, *21*(3), 1558–1562. https://doi.org/10.1016/j.concog.2012.06.015

Hesse, P. N., & Bremmer, F. (2017). The SNARC effect in two dimensions: Evidence for a frontoparallel mental number plane. *Vision Research*, *130*, 85–96. https://doi.org/10.1016/j.visres.2016.10.007

Hubbard, E. M., Piazza, M., Pinel, P., & Dehaene, S. (2005). Interactions between number and space in parietal cortex. *Nature Reviews Neuroscience*, *6*(6), 435–448. https://doi.org/10.1038/nrn1684

Ishihara, M., Keller, P., Rossetti, Y., & Prinz, W. (2008). Horizontal spatial representations of time: Evidence for the STEARC effect. *Cortex*, *44*(4), 454–461. https://doi.org/10.1016/j.cortex.2007.08.010

Lakoff, G., & Johnson, M. (2003). *Metaphors We Live By* (W. a new Afterword, Ed.). University of Chicago Press. https://press.uchicago.edu/ucp/books/book/chicago/M/bo3637992.html

Leone, M. J., Salles, A., Pulver, A., Golombek, D. A., & Sigman, M. (2018). Time drawings: Spatial representation of temporal concepts. *Consciousness and Cognition*, *59*, 10–25. https://doi.org/10.1016/j.concog.2018.01.005

Loetscher, T., Bockisch, C. J., Nicholls, M. E. R., & Brugger, P. (2010). Eye position predicts what number you have in mind. *Current Biology: CB*, *20*(6), R264-265. https://doi.org/10.1016/j.cub.2010.01.015

Lorch, R. F., & Myers, J. L. (1990). Regression analyses of repeated measures data in cognitive research. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *16*(1), 149–157. https://doi.org/10.1037/0278-7393.16.1.149

Lourenco, S. F., & Longo, M. R. (2010). General magnitude representation in human infants. *Psychological Science*, *21*(6), 873–881. https://doi.org/10.1177/0956797610370158

Nieuwenhuis, S., Forstmann, B. U., & Wagenmakers, E.-J. (2011). Erroneous analyses of interactions in neuroscience: A problem of significance. *Nature Neuroscience*, *14*(9), 1105–1107. https://doi.org/10.1038/nn.2886

Núñez, R., & Cooperrider, K. (2013). The tangle of space and time in human cognition. *Trends in Cognitive Sciences*, *17*(5), 220–229. https://doi.org/10.1016/j.tics.2013.03.008

Oldfield. (1971). *The assessment and analysis of handedness: The Edinburgh inventory—ScienceDirect*. https://www.sciencedirect.com/science/article/abs/pii/0028393271900674

Ouellet, M., Santiago, J., Funes, M. J., & Lupiáñez, J. (2010). Thinking about the future moves attention to the right. *Journal of Experimental Psychology: Human Perception and Performance*, *36*(1), 17–24. https://doi.org/10.1037/a0017176

Pitt, B., & Casasanto, D. (2020). The correlations in experience principle: How culture shapes concepts of time and number. *Journal of Experimental Psychology: General*, *149*(6), 1048–1070. https://doi.org/10.1037/xge0000696

Ruiz Fernández, S., Leonhard, T., Lachmair, M., Rolke, B., & Ulrich, R. (2014). Ruiz Fernández, S., Leonhard, T., Lachmair, M., Rolke, B., & Ulrich, R. (2014). Processing order in dual-tasks when the duration of motor responses varies [Special Issue:

Cognitive Science]. Universitas Psychologica., 12(5), doi:10.11144/Javeriana.UPSY12-5.podt. *Universitas Psychologica*, *12*.

Santiago, J., Lupáñez, J., Pérez, E., & Funes, M. J. (2007). Time (also) flies from left to right. *Psychonomic Bulletin & Review*, *14*(3), 512–516. https://doi.org/10.3758/BF03194099

Santiago, J., Román, A., & Ouellet, M. (2011). Flexible foundations of abstract thought: A review and a theory. *Spatial Dimensions of Social Thought*, 39–108. https://doi.org/10.1515/9783110254310.39

Santiago, J., Román, A., Ouellet, M., Rodríguez, N., & Pérez-Azor, P. (2010). In hindsight, life flows from left to right. *Psychological Research Psychologische Forschung*, *74*(1), 59–70. https://doi.org/10.1007/s00426-008-0220-0

Schneider, W., Eschman, A., & Zuccolotto, A. (2012). E-Prime User's Guide. *E-Prime User's Guide*.

Schwarz, W., & Keus, I. M. (2004). Moving the eyes along the mental number line: Comparing SNARC effects with saccadic and manual responses. *Perception & Psychophysics*, *66*(4), 651–664. https://doi.org/10.3758/bf03194909

Starr, A., & Srinivasan, M. (2021). The future is in front, to the right, or below: Development of spatial representations of time in three dimensions. *Cognition*, *210*, 104603. https://doi.org/10.1016/j.cognition.2021.104603

Sun, Y., Zhang, Y., Fang, Y., & Yang, W. (2023). Representations of Diagonal Timelines in English and Mandarin Speakers. *European Journal of Psychology Open*, *81*(3), 89–95. https://doi.org/10.1024/2673-8627/a000030

Teghil, A., Marc, I. B., & Boccia, M. (2021). Mental representation of autobiographical memories along the sagittal mental timeline: Evidence from spatiotemporal interference. *Psychonomic Bulletin & Review*, *28*(4), 1327–1335. https://doi.org/10.3758/s13423-021-01906-z

Topić, V., Stojić, S., & Domijan, D. (2021). An implicit task reveals space-time associations along vertical and diagonal axes. *Psychological Research*, *86*(4), 1252–1261. https://doi.org/10.1007/s00426-021-01561-y

Torralbo, A., Santiago, J., & Lupiáñez, J. (2006). Flexible conceptual projection of time onto spatial frames of reference. *Cognitive Science*, *30*(4), 745–757. https://doi.org/10.1207/s15516709cog0000_67

Tversky, B., Kugelmass, S., & Winter, A. (1991). Cross-cultural and developmental trends in graphic productions. *Cognitive Psychology*, *23*(4), 515–557. https://doi.org/10.1016/0010-0285(91)90005-9

Ulrich, R., Eikmeier, V., de la Vega, I., Ruiz Fernández, S., Alex-Ruf, S., & Maienborn, C. (2012). With the past behind and the future ahead: Back-to-front representation of past and future sentences. *Memory & Cognition*, *40*(3), 483–495. https://doi.org/10.3758/s13421-011-0162-4

Vallesi, A., Binns, M. A., & Shallice, T. (2008). An effect of spatial–temporal association of response codes: Understanding the cognitive representations of time. *Cognition, 107*(2), 501–527. https://doi.org/10.1016/j.cognition.2007.10.011

von Sobbe, L., Scheifele, E., Maienborn, C., & Ulrich, R. (2019). The Space-Time Congruency Effect: A Meta-Analysis. *Cognitive Science*, *43*(1), e12709. https://doi.org/10.1111/cogs.12709

Weger, U. W., & Pratt, J. (2008). Time flies like an arrow: Space-time compatibility effects suggest the use of a mental timeline. *Psychonomic Bulletin & Review*, *15*(2), 426–430. https://doi.org/10.3758/PBR.15.2.426

Winter, B., Matlock, T., Shaki, S., & Fischer, M. H. (2015). Mental number space in three dimensions. *Neuroscience & Biobehavioral Reviews*, *57*, 209–219. https://doi.org/10.1016/j.neubiorev.2015.09.005

Wood, G., Willmes, K., Nuerk, H.-C., & Fischer, M. (2008). On the cognitive link between space and number: A meta-analysis of the SNARC effect. *Psychology Science Quarterly*, *50*.

Woodin, G., & Winter, B. (2018). Placing Abstract Concepts in Space: Quantity, Time and Emotional Valence. *Frontiers in Psychology*, *9*, 2169. https://doi.org/10.3389/fpsyg.2018.02169