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Past on the ground floor and Future in the attic: The Vertical Mental TimeLine

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ABSTRACT

Time is represented along a horizontal mental line with an association between the past (or short duration) and left space as well as between the future (or long duration) and right space. A possible vertical time representation is also supposed to exist, even if results are contradictory depending on the stimuli and response keys used. The aim of the present study was to test the presence of a vertical representation of temporal expressions, overcoming possible methodological limits. In Experiment 1, 167 Italian students had to categorize 20 Italian temporal expressions that appeared at the center of the screen with two analogous vertical response keys ("down" and "up" arrows of a regular keyboard). Specifically, in Experiment 1a participants pressed the "down" arrow with their left hand and the "up" arrow with their right hand, whereas in Experiment 1b the key-hand assignment was reversed. In Experiment 2, 25 participants underwent the same procedure using a vertically-positioned response box. The same participants also performed a Time-To-Position task, in which they located temporal expressions along a vertical line. In both experiments, a space-time interaction was found, with an association between past expressions and the bottom (or "down" arrow) response key as well as between future expressions and the top (or "up" arrow) key. The results suggest a bottom-to-top mapping of time representation, according to the "more is up" metaphor.

Keywords: STEARC effect; Vertical Time Representation; More Is Up Metaphor; Temporal Judgement Task; SPoARC effect.

Public Significance Statement

The present study suggests that a vertical mental timeline representation exists, showing a space-time association from bottom to top. This mental representation is probably influenced by the daily life experience of verticality in the physical world, such as the construction of a building from the ground floor to the attic, according to the "more-is-up" metaphor. The results were confirmed using both an analogous and a literal concept of verticality in a temporal judgment task, and this bottom-to-top representation of time was not influenced by the hand used to press the response button. Moreover, we confirmed not only that the past was associated with the bottom space and the future was associated with the top space, but also that the temporal expressions used in this study showed an ordinal pattern when participants performed a Time-to-Position task. Therefore, we can conclude that, even if temporal expressions do not refer to a fixed moments in the time, they occupy a specific position on the mental timeline with a "specific order".

Introduction

In nearly three decades, several studies have focused on the interactions between space, time, and numbers, with their findings elucidating cognitive representations of these fundamental concepts (Winter et al., 2015a, 2015b). For instance, the most frequently-used evidence for the interaction between space and numerical magnitude is the well-known *Spatial-Numerical Association of Response Codes* (SNARC) effect (Dehaene et al., 1993). This effect reflects an association between small numbers and the left-hand side and large numbers and the right-hand side (Dehaene et al., 1993). The SNARC effect is commonly seen as support for the concept of a mental number line (MNL) oriented from left to right or right to left (Fabbri & Guarini, 2016; Winter et al., 2015b; Wood et al., 2008). In addition, the above-mentioned SNARC effect has been observed for the vertical axis with a preference for large numbers at the top and small numbers at the bottom (Aleotti et al., 2020; Cappelletti et al., 2007; Fabbri, 2011, 2013; Gevers et al., 2006; Hesse & Bremmer, 2017; Holmes & Lourenco, 2011, 2012; Ito & Hatta, 2004; Müller & Schwarz, 2007; Schwarz & Keus, 2004; Shaki & Fischer, 2012; Sixtus et al., 2019; Winter & Matlock, 2013; Winter et al., 2015a,b).

In a similar way, a horizontal space-time interaction has been documented, reflecting a *Spatial-TEmporal Association of Response Codes* (STEARC) effect (Beracci et al., 2021a; Bonato et al., 2012; Fabbri et al., 2012; Fabbri et al., 2013a,b; Ishihara et al., 2008; Vallesi et al., 2008). The STEARC effect reflects an association between past/short durations and the left space and between future/long durations and the right space (Bonato et al., 2012; Macnamara et al., 2018; von Sobbe et al., 2019; Winter et al., 2015a). Indeed, the space-time interaction has been confirmed using different temporal materials, such as visual or auditory temporal durations (lasting milliseconds or seconds; Fabbri et al., 2012, 2013a,b; Ishihara et al., 2008), temporal verbs or expressions (Beracci et al., 2021a; Bottini & Casasanto, 2013, Santiago et al., 2007; Torralbo et al., 2006), or moments of the day (such as breakfast, lunch, and dinner; Tversky et al., 1991). Thus, the STEARC effect supports the idea that humans represent time along a spatially-oriented mental timeline or MTL (Beracci et al., 2021a; Bonato et al., 2012; Di Bono et al., 2012; Ishihara et al, 2008; Weger & Pratt, 2008), from left to right or from right to left, in line with the cultural direction of reading and writing (Casasanto & Bottini, 2013; Chen, 2007; Fuhrman & Boroditsky, 2010; Pitt & Casasanto, 2020; Vallesi et al., 2011). The STEARC effect has also been found along the vertical axis (Beracci et al., 2021b; Bergen & Chan Lau, 2012; Fuhrman & Boroditsky, 2010; Hartmann et al., 2014; He et al., 2018; Leone et al., 2018; Ruiz Fernandéz et al., 2014; Stocker et al., 2016; Topić et al., 2021; Woodin & Winter, 2018), suggesting either a bottom-to-top or a top-to-bottom time representation.

The nature of the SNARC (or SNARC-like) and STEARC effects is still widely debated, and many theories have been proposed to explain the relationship between numerical/temporal magnitude and space. Firstly, the ATOM (*A Theory Of Magnitude*; Walsh, 2003, 2015) model proposes that space, time, and numbers are linked by a common underlying mechanism devoted to magnitude processing (Fabbri et al., 2012). Thus, the SNARC or STEARC effect is a specific case of a broader *Spatial-Quantity Association of Response Codes* (SQUARC) effect, suggesting a general association between space and magnitude. The SNARC-like effect has been shown for different non-numerical dimensions (Macnamara et al., 2018), such as pitch height (e.g., Cho et al., 2012), loudness (e.g., Chang & Cho, 2015), luminance (e.g., Fumarola et al., 2014), size (e.g., Ren et al., 2011), and weight (e.g., Dalmaso & Vicovaro, 2019). Imaging studies in humans have showed that the right posterior parietal cortex (PPC), especially the posterior part along the intraparietal sulcus (IPS), might contain the neural substrate of a generalized magnitude system for space, time, numbers, and other types of magnitude (Bueti & Walsh, 2009; Cohen Kadosh et al., 2007a,b; Walsh, 2003). Even if the ATOM model predicts a smaller-left/bottom and a larger-right/top association between magnitudes and space, to the best of our knowledge the possible vertical representation of non-numerical magnitudes seems to be mainly confined to a few studies (Bruzzi et al., 2017; Vicovaro & Dalmaso, 2021), with no clear result pattern (e.g., loudness associated with high space and quietness associated with low space in Bruzzi et al., 2017 vs. lighter and heavier weights associated with both down and top space, depending on task context, in Vicovaro & Dalmaso, 2021). Moreover, the ATOM model could predict the spatial representation of quantities when magnitudes (e.g., temporal durations) are used but is limited when task stimuli are not magnitudes (as in the present study).

The horizontal and vertical SNARC-like effects could also be explained by the polarity correspondence account proposed by Proctor and Cho (2006). According to the authors, for a variety of binary classification tasks (e.g., larger/smaller than 5 or past/future judgments), participants code the stimulus alternatives and response alternatives as (+) polarity and (-) polarity, and response selection is faster when the polarities correspond than when they do not. Specifically, smaller numbers/past events/short durations and left/bottom responses are coded as negative polarities, whereas larger numbers/future events/long durations and right/top responses are coded as positive polarities. Thus, responses are faster when the stimulus and the response polarities are identical (i.e., small/past/short and left/bottom as well as large/future/long and right/top) compared to when they are different (i.e., small/past/short and right/top as well as large/future/long and left/bottom). Nevertheless, some recent studies have cast doubt on whether polarity correspondence is able to provide an exhaustive account of SNARC-like effects (e.g., Di Rosa et al., 2017; Leth-Steensen & Citta, 2016; Santiago & Lakens, 2015).

An alternative explanation, the verbal working memory account (Abrahamse et al., 2016; Fias & van Dijck, 2016), proposes that the SNARC effect arises from positional spatial codes along left-to-right oriented series of items, ordered in verbal working memory (i.e., ordinal information). Thus, the interaction between serial order in working memory and spatial processing has been shown, as suggested by the *Spatial-Positional Association of Response Codes* (SPoARC) effect found by Ginsburg and colleagues (Ginsburg et al., 2014; Ginsburg & Gevers, 2015). The authors showed that left-hand responses were faster for the numbers presented in the first few positions of a sequence displayed to the participants (instead of a smaller magnitude) and right-hand responses were faster for the last few numbers presented in the sequence (instead of a larger magnitude). This verbal working memory account could predict the STEARC effect, considering that there is the habit of placing earlier "events" in the left mental space followed by later "events" located more to the right, in order to obtain maximal internal coherence (Santiago et al., 2011). For instance, Santiago et al. (2010) found that, in three experiments, scenes of movies and sequences of everyday activities were associated with left-right orientations, with scenes or activities placed (ordered) before the comparison stimulus associated with the left space, whereas scenes or activities placed (ordered) after the comparison stimulus were associated with the right space. Although the verbal working memory account seems to be limited in its capacity to explain the vertical representation of numbers (e.g., Aleotti et al., 2020), the SPoARC-like effect has been observed in vertical (bottom-to-top) representation of abstract concepts (Abrahmse et al., 2014; Zhou et al., 2019). Taking into account that the temporal concepts can be classified into deictic time (D-time), sequence time (S-time), and duration (T-span; Núňez & Cooperrider, 2013), the verbal working memory account could be adequate to explain horizontal and vertical time representations when temporal stimuli are defined as earlier/later (than an activity) or shorter/longer (than a fixed middle duration), with both implying an ordered sequence of events or time, while it does not predict horizontal and vertical space-time associations when past/future stimuli (which are not ordered in a fixed manner) are used.

Within cognitive linguistics, the Conceptual Metaphor theory explains the association between space and time or number (Lakoff, 1987; Lakoff & Johnson, 1980, 1999). Within this view, metaphor links abstract concepts to concrete sensory experiences. In other words, abstract concepts are hypothesized to be structured through metaphoric mapping from concrete domains. Such mappings arise because of experienced correlations between the processing of the concrete and the abstract domains (see also Pitt & Casasanto, 2020 with the *CORrelations in Experience* or CORE principle). Vertical associations assume that abstract concepts are represented through concrete sensorimotor experiences with the physical world. Based on common experience, it is reasonable to expect a vertical (bottom-to-top) representation of abstract concepts (Hartmann et al., 2012). Thus, the conceptualization of quantities could be related to the metaphor "*more is up*" (Lakoff, 1987; Lakoff & Johnson, 1980, 1999), which is embodied in experienced correlations, for example, between height and amount of substance (Santiago et al., 2011). As regards time, people often have experiences in daily life along a vertical orientation, such as the growth process of a child to adulthood, or that of a seedling to a plant, or the arrangement of buildings with several floors from the ground floor to the attic (Santiago et al., 2011). Thus, it is not surprising that we also find some linguistic time expressions along the vertical axis, such as "*Christmas is coming up*" (Lakoff & Johnson, 1980). This view is in line with the theory of Tropic, Embodied and Situated Theory of cognition (TEST; Myachykov et al., 2014) and with the broader theoretical framework of grounded cognition (e.g., Barsalou, 2008). According to TEST, for instance, the vertical SNARC effect arises from a tropic representation of quantities due to the constraints presented in the physical world, such as the action of piling up objects in line with the "more-is-up" metaphor (Fischer, 2012; Gevers et al., 2006; Holmes & Lourenco, 2012; Shaki & Fischer, 2012, 2018; Winter & Matlock, 2013). Both the "more-is-up" metaphor and the TEST theory nicely predict a vertical STEARC effect, in a bottom-to-top direction, because of our daily experience along a vertical dimension.

However, studies investigating the vertical representation of time have obtained contradictory results, and a clear picture has not been defined. For example, Ishihara et al. (2008) who, in their second experiment, asked participants to indicate whether the timing of an auditory stimulus was earlier or later than a preceding stimuli, failed to find a vertical space-time association when the response-button arrangement along the vertical axis was set in the transverse plane over a computer keyboard placed on a table (see Casasanto & Bottini, 2013; Hartmann & Mast, 2012; Kolesari & Carlson, 2018; Miles et al., 2011; for similar results), suggesting only a horizontal STEARC effect (Bonato et al., 2012). In line with this finding, Tversky et al. (1991) and Woodin and Winter (2018) found that participants with free response options (e.g., placing stickers spontaneously on any part of a page) preferred to represent time (e.g., moments of the day) along a horizontal axis. On the contrary, Leone, Salles, Pulver, Golombek and Sigman (2018) suggested that participants ordered the words "past", "present", and "future" chronologically upward, showing a vertical mental time representation. In a similar way, Ruiz-Fernandéz, Lachmair and Rahona (2014) reported that participants were quicker to respond to a square positioned in the upper space when it was paired with a word referring to the future and faster in their response to a square positioned in the lower space when it was paired with a word that referred to the past, suggesting a bottom-to-top time representation. In a similar way, Beracci et al. (2021b) reported a bottom-to-top representation for temporal durations in the millisecond range, probably according to the "more-is-up" metaphor. Finally, several studies have reported that the past is mapped at the top and the future is mapped at the bottom (Boroditsky, 2001; He et al., 2018; Topić et al., 2021) in explicit and implicit tasks, suggesting an automatic activation of a temporal concept along a top-to-bottom orientation, reflecting the salience of the experience with falling objects (i.e., the law of gravity).

A possible explanation of these contradictory results could be related to the type of temporal stimuli used. The studies in which the vertical space-time association was not found used past-related (e.g., "*World War II*", "*11 September 2001*", "*childhood*") and future-related (e.g., "*holidays on Mars*", "*marriage*") verbal stimuli (Hartmann & Mast, 2012) or pictures of buildings and cities (e.g., ancient ruins for the past and science fiction scenes for the future). On the other hand, the vertical space-time association was found using temporal stimuli recalling a mental temporal progression rather than "fixed moments" in time. Indeed, stimuli such as time statements using "before/after" or "earlier/later" (e.g., "*March comes earlier than April*", Boroditsky, 2001; "*Monday is before Wednesday*", Chen, 2007), printed pictures showing a temporal progression (e.g., "*cards depicting stages of plant development*", Bergen & Chan Lau, 2012; "*cards depicting an apple being eaten*", Fuhrman & Boroditsky, 2010), and target objects (e.g., orange or colored rectangles) with a variable duration from 200 ms to 1500 ms (Beracci et al., 2021b; Topić et al., 2021) seemed to be more suitable for showing a space-time interaction along the vertical axis. In the present study, we decided to use 20 Italian temporal expressions (e.g., "*ieri*" for yesterday or "*dopo*" for after) derived from a selection of stimuli used by Santiago et al. (2007, p. 516) and reported in the Appendix, and from stimuli used in the study by Rolke et al. (2013, p. 13), that can be found in Table 2 of their paper. These temporal expressions define temporal information such as past/future, without a specific (or predefined) ordinal sequence. The choice of these stimuli was also motivated by the contrasting results found in two different studies. In one study, Woodin and Winter (2018) used a piece of A4 paper with a pair of central axes (or empty page) and participants were free to position a set of quantity words ("most", "more", "less" and "least"), numbers ("2", "4", "7" and "9"), time words ("past", "future", "earliest", "earlier", "later", "latest"), and emotional valence words ("best", "better", "worse", "worst"). The authors reported a preference for a horizontal arrangement for numbers and time concepts, whereas the vertical arrangement was preferred for quantity words and emotional valence. By contrast, Leone et al. (2018) investigated how people freely represented temporal events with different time granularities: zones of time (past, present, and future), seasons, days of the week, part of the day, and timeline of personal and historical events. The main result, for the purpose of the present study, was that the different time categories were represented along both horizontal (from left to right) and vertical (from bottom to top) axes (and this result pattern was mainly observed for zones of time). However, the choice to use a page or screen, in which both horizontal and vertical (as well as both diagonal axes) are present, does not allow us to investigate how the temporal stimuli are represented along the vertical dimension, considering the contrasting results in terms of the superiority of the horizontal spatial-temporal association compared to the vertical spatial-temporal association (Boroditsky, 2001; Casasanto & Bottini, 2013; Chen, 2007; He et al., 2018). Thus, in the present study, we used a single vertical line, and this choice could increase the possibility of adopting a vertical dimension in representing time. In addition, the studies by Leone et al. (2018) and by Woodin and Winter (2018) adopted few and different temporal expressions, reducing any possibility of reaching a specific pattern of time representation along a vertical line. Hence, in Experiment 2, participants were requested to perform a Time-To-Position task, in which 20 temporal expressions (also presented in the bimanual response task) were to be freely placed along a vertical line from the bottom part of the line (referring to "*distant past*") to the top part of the line (referring to "*distant future*"). This task may be able to verify the vertical mapping of the MTL, leaving participants free to express their own representation vertically, confirming (or not) the results provided by bimanual speeded responses.

From a methodological point of view, the contradictory results reviewed above could also depend on how verticality (e.g., Tversky, 2011) was indicated by the response mode, especially when using bimanual speeded responses. In line with the literature regarding the SNARC effect, vertical mapping could be defined as: (a) an analogous concept of the term "vertical" in a two-dimensional context in which the vertical axis is defined by two keys placed horizontally (e.g., on a numerical keypad positioned horizontally, the "2" key is the "down" key whereas the "8" key is the "up" key, or, on a regular keyboard, "up" and "down" are represented by the arrow keys), resembling the sagittal (radial or distance-based) axis (i.e., near and far; Winter et al., 2015b) and (b) a literal concept of the term "vertical" in a 3-D context when, for example, the keyboard is positioned vertically. In the numerical domain, the question of analogous (e.g., radial) and literal concepts of verticality has been addressed in the past two decades (Hartmann et al., 2014; Holmes & Lourenco, 2011, 2012; Winter et al., 2015b). For example, several studies have interpreted results in term of (true) vertical SNARC effect, when participants pressed two response buttons positioned on a horizontal plane, in which the "far" button represented the "up key" while the "near" button represented the "down key" (Gevers et al., 2006; Ito & Hatta, 2004; Müller & Schwarz, 2007; Shaki & Fischer, 2012). When response buttons were vertically arranged (without any possible confounding association between down/near and up/far), Aleotti et al. (2020) and Hartmann et al.

(2014) reported a vertical SNARC effect, with a bottom-to-top numerical representation, similar to that reported in other studies. However, Holmes and Lourenco (2012) confirmed the vertical SNARC effect only when the vertical space was primed, such as the levels in a building, suggesting that the vertical representation of numbers is not spontaneous. Thus, it remains to further address this aspect of analogous (e.g., radial) vs. literal concept of vertical space in the time domain.

It is clear, then, that this methodological aspect has to be taken into account to disentangle the results regarding the vertical axis. Indeed, Ishihara et al. (2008) and Miles et al. (2011) did not report any vertical STEARC effect, probably because in the former study a keyboard was placed perpendicularly to the participant's trunk and in the latter study a standard numeric keypad was mounted on an incline with "2" and "8" as response keys, suggesting an analogous concept of verticality (but see Beracci et al., 2021b, for different results). Hartmann and Mast (2012), who did not find a vertical space-time interaction, used an external device for the responses while participants were seated on a motion platform. Thus, this separation between response device and motion (vertical) platform could explain the null effect on vertical time representation. Consequently, in the two different experiments of the present study, we used the directional (down/up) arrows (i.e., analogous representation of verticality; Experiment 1) and an external response box positioned vertically (i.e., literal concept of the term verticality; Experiment 2) in order to increase "the sense of verticality" of the response keys, thus overcoming this methodological limit of the previous studies (Beracci et al., 2021b; Hartmann & Mast, 2012; Ishihara et al., 2008; Miles et al., 2011). In addition, the choice of using these response modalities could also provide a comparison of the analogous vs. literal concept of vertical space (provided by the response keys) when observing (or not) the vertical representation of time.

However, the hand used to respond is another possible confounding effect to be controlled for. Indeed, there are contrasting results regarding the relative contribution of spatial reference frames (i.e., extracorporeal spatial information vs. anatomical information) to the emergence of the SNARC effect (Viarouge et al., 2014). For instance, when the vertical representation of numbers was investigated, Ito and Hatta (2004) performed two experiments in which the hand-key assignment was controlled (i.e., in one experiment the left hand was assigned to the bottom key and the right hand to the top key, while in another experiment the opposite assignment of response hand was adopted). This methodological issue could indicate how the vertical time representation is related to extracorporeal space (spatial position of buttons with respect to the body; see also Shaki & Fischer, 2012). However, other studies reported that the spatial-numerical association along the vertical axis was represented in terms of the specific spatial representation of the hands on the basis of the task setting/instruction created (e.g., Casasanto, 2009; Hartmann et al., 2014; Müller &

Schwarz, 2007). Considering that this methodological issue was not controlled for in previous studies (but see Beracci et al., 2021b for this methodological issue) in which vertical space-time interaction was studied (in 2008 Ishihara et al. asked all participants to press the bottom key with their left hand and the top key with their right key; in 2011 Miles et al. asked participants to press the down/up keys with right hand fingers), we performed two versions of Experiment 1 modifying the hand-key assignments.

Motivated by these methodological aspects, we asked participants in two studies to perform a classic temporal judgment task with 20 Italian temporal expressions. The temporal expressions were located at the center of the screen each time, and participants used either the up and down arrows of a standard keyboard (Experiments 1a and 1b), or two response buttons displayed vertically on a vertically-positioned response box (Experiment 2). In this last experiment, participants also performed a Time-To-Position task in which the temporal expressions were to be freely placed along a vertical line, in order to disentangle contrasting results with this type of free task and to confirm the results of a (speeded) temporal judgment task. According to the experimental procedure used in both experiments, we predicted a STEARC effect due to the spatial mapping of the response buttons being considered vertically in both the analogous and literal concepts. This vertical spatial-temporal association should also be expected in the Time-To-Position task. Taking into account the temporal stimuli and the control experimental procedure adopted in experiments, a bottom-to-top representation of time was also expected.

Experiment 1A

The aim of this first Experiment was to observe a vertical time representation, using a classical temporal task. Specifically, the temporal expression, referring to the past or future (see Appendix) was presented at the center of the screen each time. The participants performed the temporal discrimination task twice, with two response buttons representing vertical space (i.e., spatial arrows). A vertical STEARC effect was expected (Beracci et al., 2021b).

Materials and Methods

All data (file name: Data Beracci & Fabbri) reported in this paper are available for download via the following Open Science Framework repository: https://osf.io/7jckp/quickfiles

Participants

A statistical power analysis with G*Power 3.1 (Erdfelder et al., 1996) was performed for sample size estimation based on data from a meta-analysis on the space-time congruency effect (von Sobbe et al., 2019). The effect size in this study was 0.46, considered to be medium using

Cohen's (1988) criteria. With an alpha = .05 and power = .80, the projected sample size needed with this effect was approximately N = 12 for the within group comparison. However, to negate the loss of statistical power associated with a small sample, we also calculated the mean number of participants enrolled in the studies within the literature reviewed. In general, a mean of 40.69 participants was considered (from 10 English participants in Bergen and Chan Lau in 2012 to 122 participants in Woodin and Winter in 2018 in a web experiment). Thus, we recruited a group of ninety-nine Italian students (87 females; mean age = 22.76 years; SD = 2.08 years) for participation in an online study, in exchange for course credits. The participants filled in the Edinburgh Handedness Inventory (EHI; Oldfield, 1971). Based on the EHI scores, 93 participants were right-handed (M = 60.20; SD = 37.48) and 6 were left-handed (M = -53.00; SD = 30.33). Data from 13 participants (12 females and 1 male; see Procedure section below) were not included because their performance accuracy was on average equal to 75.66%, which was lower than that of the participants who were included, who showed an average performance of 93.68% ($t(97) = -7.89$; $p = .0001$). Thus, the data for the remaining 86 participants (75 females; mean age = 22.81 years; SD = 2.17 years; 81 right-handed) were analyzed. All participants had normal or corrected-to-normal vision and were not informed as 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 PsyToolkit software (version 2.6.1) that allows for the design, programming, and setting up of online surveys, and the embedding of reaction time experiments (Stoet, 2010, 2017). The reaction time (RT) 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.

All stimuli were presented in the browser window and responses were measured using a regular keyboard ("down" and "up" arrow keys). Considering that participants used their devices (personal computer or laptop) with different screen sizes, the stimuli in the online response time experiment were presented in an 800 by 600 pixel area in the browser. The fixation stimulus was a white plus (+) symbol (184 pixels wide x 175 pixels high). All stimuli were in white, presented on a black background. The stimuli consisted of 20 Italian temporal expressions (564 pixels wide x 195 pixels high), 10 referring to the past (e.g., "*ieri*", English translation: "yesterday") and 10 to the future (e.g., "*domani*", English translation: "tomorrow"), that appeared at the center of the screen each time. As already mentioned above, we initially selected the stimuli used by Santiago et al. (2007). We therefore chose 14 Spanish expressions (7 for the past and 7 for the future) from the 28 used by Santiago et al. (2007). We excluded all stimuli in which a specific verb was conjugated in time (e.g., "*I spoke*" or "*I will speak*") because we preferred to use temporal adverbs or locutions/substantives, given that these types of temporal expressions are usually used to refer to the past or future. Then, we selected 24 Dutch expressions (12 for the past and 12 for the future) from the 30 time-reference words used by Rolke et al. (2013), following the same principle. After the translation from Spanish/Dutch into the Italian language, we finally selected the 20 temporal stimuli on the basis of the number of letters (past: 9.10 ± 3.31 vs. future: 9.40 ± 4.06, $t(18) = -0.18$, $p = .86$, Cohen's $d = 0.08$), number of syllables (past: 3.80 ± 1.32 vs. future: 4.00 ± 1.49, $t(18) = -0.32$, $p = .75$, Cohen's $d = 0.001$) and frequency of use (past: 94.60 ± 5.58 vs. future: 91.80 ± 8.78, $t(18) = 0.85$, $p = .41$, Cohen's $d = 0.004$).

Procedure

After consenting to participate by clicking a tickbox, participants were required to categorize the targets (20 temporal expressions) and were instructed to press the down and up arrows of the standard keyboard as response keys, with the left and right hand, respectively. The fixation stimulus (+) appeared at the center of the screen for 1000 ms. After the fixation point, a temporal word (the target stimulus) appeared centrally on the screen. In all trials the target lasted 5000 ms or until an individual response had been recorded. The task was performed twice, using two different blocks, in which the instruction–key assignments were counterbalanced. In one block, the "down" key was pressed with the left hand in order to categorize the past, while the "up" key was to be pressed with the right hand to categorize the future. In the other block, the "down" key was pressed with the left hand in order to categorize future temporal expressions, and the "up" key was pressed with the right hand to categorize past temporal expressions. The order of blocks was counterbalanced within participants. In each block, 180 trials (20 stimuli repeated 9 times; Beracci et al., 2021a) were presented in a random order. Thus, altogether, each participant judged 360 trials. Before the test, a training session was run with 10 trials. The experimental procedure lasted approximately 20 min. Considering that not only did we perform an online experiment, but also that we used a metaphoric concept of verticality, at the end of temporal judgment task participants were asked to answer an ad-hoc question in order to verify their real perception of the response keys ("down"/"up" arrows) used in the study ("*How did you really perceive the response keys ("down"/"up" arrows) used in the experiment?*"), using a 5-point Likert scale (from 1= always/definitely vertically to 5= always/definitely radially).

Data Analysis

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 4%). A two-way repeated measures ANOVA was carried out on RTs and accuracy (defined as number of errors or NEs), with Temporal Expression (past vs. future) x Response Position ("down" key vs. "up" key) as within-subjects factors. The criterion set for statistical significance was $p < .05$ and we report the effect size (as eta partial square η^2_p). Subsequently, we compared the congruency effects, separately for past (dRT Past= RT down arrow - RT up arrow) and future (dRT Future= RT up arrow – RT down arrow), with a within-subjects t-test, in order to see whether there were differences between them.

Results

All descriptive data for RTs and accuracy (with their relative standard deviation or SD) are displayed in Figure 1.

The Temporal Expression x Response Position ANOVA on RTs[1] revealed no significant main effect for Response Position ($F(1, 85) = 3.44$, $p = .07$, $\eta^2_p = 0.04$), but a significant main effect for Temporal Expression ($F(1, 85) = 4.23$, $p < .05$, $\eta^2_p = 0.05$) was present, with faster responses for the future (M = 1069 ms; SD = 276 ms) than for the past (M = 1087 ms; SD = 265 ms). There was also a significant Temporal Expression x Response Position interaction ($F(1, 85) = 22.42$, $p < .0001$, $\eta^2_p = 0.21$), suggesting a clear congruency effect between the time and the response position. As displayed in Figure 1a, participants responded faster with the "down" key for temporal words referring to the past than with the "up" key, and responses were also faster using the "up" key for future words compared to the "down" key, with $p < .05$ for all comparisons, suggesting a time representation from bottom-to-top on a vertical MTL.

The same ANOVA on NEs[2], showed neither significant main effects (all *F*s < 0.90 with *p*s > .35, $\eta^2_{ps} < 0.01$) nor significant interactions, $F(1, 85) = 3.64$, $p = 0.06$, $\eta^2_p = 0.04$ (Figure 1b).

[1] The Temporal Expression x Response Position ANOVA was also performed on the total sample (N=99). Results showed no significant main effect for Temporal Expression ($F(1, 98) = 2.09$, $p = .15$, $\eta^2 p = 0.02$), but did show a significant main effect for the Response Position ($F(1, 98) = 4.96$, $p < .05$, , $\eta^2 p = 0.05$), with faster responses with the "up" key (M = 1079 ms; SD = 269 ms) than with the "down" key (M = 1094 ms; SD = 285 ms). There was also a significant Temporal Expression x Response Position interaction ($F(1, 98) = 25.07$, $p < .0001$, $\eta^2 p = 0.20$). The results showed that participants responded faster with the "down" key for temporal words referring to the past (M= 1048 ms; SD= 251 ms) than with the "up" key (M=1139 ms; SD= 291 ms), and responded faster with the "up" key for future words (M= 1020 ms; SD= 247 ms) than with the "down" key (M=1141 ms; SD= 320 ms), suggesting a congruency effect with a vertical upward mapping, also in the total sample.

[2] The same ANOVA on NEs performed on the total sample (N=99), showed neither significant main effects (all *F*s < 3.98 with *p*s > .05, $\eta^2 ps < 0.04$) nor significant interactions ($F(1, 98) = 0.62$, $p = 0.43$, $\eta^2 p = 0.01$).

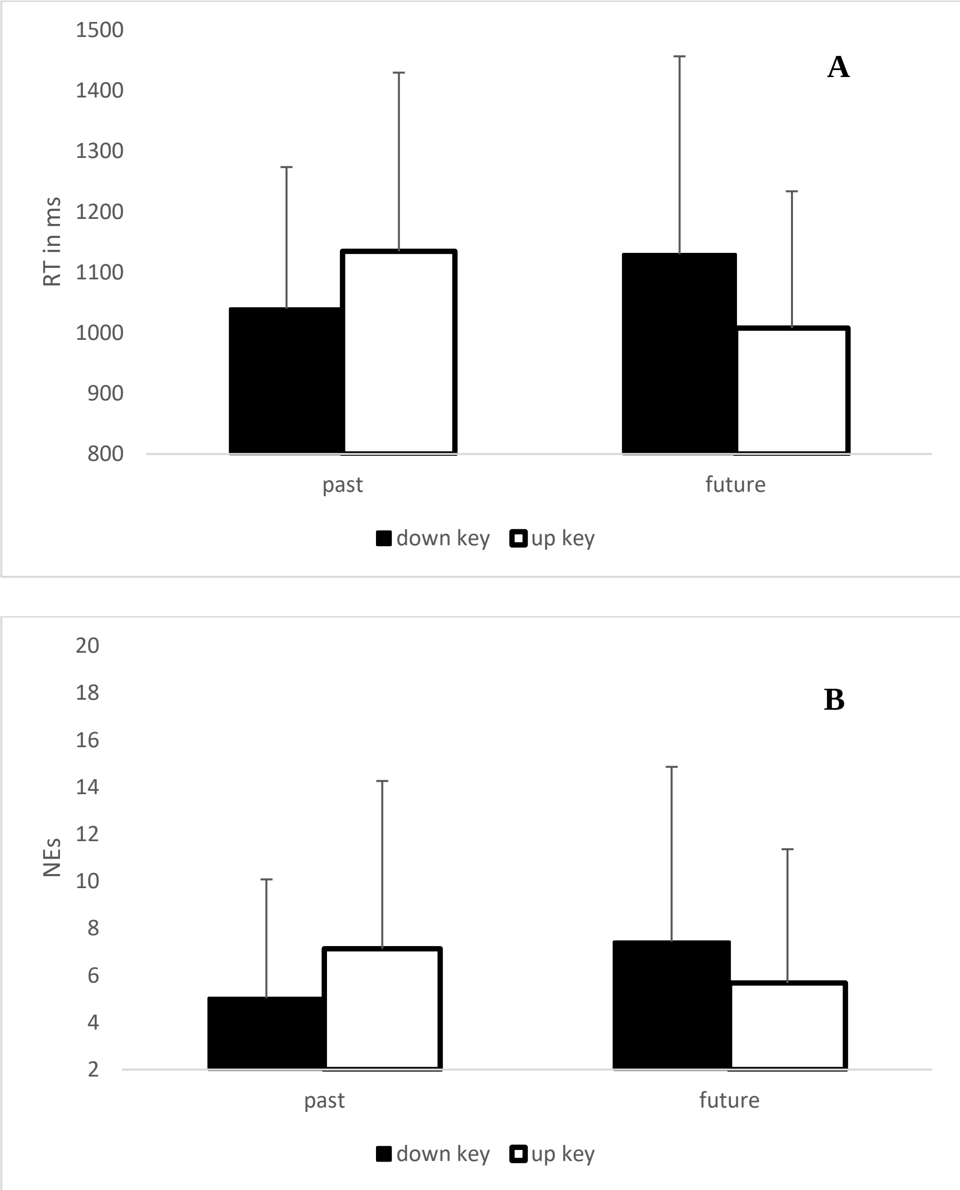


Figure 1. A) the mean RTs for past and future expressions judged with the down key (black histogram) and up key (white histogram) for Experiment 1a; **B)** the mean NEs for past and future expressions judged with the down key (black histogram) and up key (white histogram) for Experiment 1a. In both figures, the bars represent SD.

Moreover, the comparison between the dRT Past (M = -95 ms; SD = 200 ms) and dRT Future (M = -121 ms; SD = 242 ms) showed no differences between the two congruency effects, $t(85) = 1.85$ $p = 0.07$, Cohen's $d = 0.12$.

As regards the survey[3], 92% of participants responded that they definitely perceived the keys in terms of verticality (choice 1), or that they seemed more vertical than radial (choice 2), while 8% of participants responded that they perceived the response keys indifferently in terms of verticality or radiality (choice 3).

Discussion

We studied a space-time interaction along the vertical axis, using a temporal judgement task with temporal expressions positioned in the center of the screen. The vertical dimension was provided by the spatial arrows of a standard keyboard, even if these response keys represented an analogous concept of verticality.

Our results showed a clear STEARC effect along the vertical axis (Beracci et al., 2021b; Leone et al., 2018; Ruiz-Fernandéz et al., 2014) with an association between the past and the bottom key and between the future and the top key, suggesting a vertical MTL that goes from bottom-to-top. In our opinion, it could have been both the types of temporal expression presented (past/future stimuli) and the response keys selected (the directional arrows) that induced our vertical STEARC effect. This assumption was corroborated by participants' responses in the ad-hoc survey: about 90% of participants reported that they perceived the response keys used in the study as being arranged vertically. As we expected, we found a vertical STEARC effect because participants used the directional "down" and "up" arrows, which represented verticality, suggesting a mental time representation along this axis. Although this result pattern could be in line with the ATOM model (Walsh, 2003, 2015) that predicts an association between smaller quantities and bottom spaces and between larger quantities and top spaces, we did not use any specific quantities, such as numbers (Dehaene et al., 1993), temporal durations (Ishihara et al., 2008), size (Ren et al., 2011) or weight (Vicovaro & Dalmaso, 2021), but manipulated time at a more "conceptual" level. Thus, the vertical STEARC effect probably supported the "more is up" metaphor (Lakoff, 1987) for the temporal domain, also in line with TEST theory (Fischer, 2012; Myachykov et al., 2014). According to this account, time is grounded in vertical space, probably because of the relationship between the abstract concept of magnitude and the process of accumulating objects or substances (e.g., pouring liquid into a glass), and the bottom-to-top orientation seems to be universal and does not depend on cultural habits (Myachykov et al., 2014). It is worth noting that we found a bottom-to-top instead of a top-to-bottom direction as found by Topić et al. (2021). Most probably, the fact that in our experiment the only vertical information was provided by up/down response buttons compared to a

[3] When all participants were considered, 91% of participants selected option 1 (definitely vertically) or 2 (more vertically than radially), 7% selected option 3 (it was indifferent), and 2% of participants selected option 4 (more radially than vertically) or 5 (definitely radially).

(wide) search array, in which both cardinal axes are presented, could explain the discrepancy of the findings reported. The “more is up” metaphor seemed to be the best account to explain our results considering that Santiago and Lakens (2015) challenged the efficacy of the polarity correspondence account to explain the vertical STEARC effect, and that our stimuli did not provide any spatialization (i.e., our stimuli were categorized as past/future) reducing the involvement of a SPoARC-like effect.

However, Experiment 1A contained a procedural limit. We asked participants to judge whether each expression referred to the past or future by pressing the down arrow with the left hand and the up arrow with the right hand in each experimental block. This procedure may produce a confounding variable between the spatial location of response (bottom or top) and response hand (see Ito & Hatta, 2004 for a similar procedure in the numerical domain). Thus, the vertical STEARC effect observed might reflect an association between past and left hand and between future and right hand, suggesting a transposition of the horizontal time representation (Bonato et al., 2012; Bottini & Casasanto, 2013; Fabbri et al., 2012, 2013a,b; Ishihara et al., 2008; Santiago et al., 2007; Torralbo et al., 2006; Vallesi et al., 2008; Weger & Pratt, 2008) into vertical space. Both spatio-anatomical (hand-based) and extracorporeal (location) hypotheses (see, Viarouge et al., 2014 for a review about spatial reference frames involved in the SNARC effect) should be addressed for the vertical STEARC effect (but see Beracci et al., 2021b for preliminary results). In order to rule out this possibility, we performed the same experiment with the instruction that the right hand should be used to press the bottom key while the left hand should press the top key. In this way, a replication of the previous results would confirm a vertical STEARC effect, supporting the theory that extracorporeal spatial information regarding a spatial-temporal association was related to the STEARC effect. By contrast, the lack of a significant interaction would indicate that the results of Experiment 1A reflected a horizontal time representation based on the hands used to respond (i.e., spatio-anatomical hypothesis).

EXPERIMENT 1B

The aim of Experiment 1B was to investigate the vertical STEARC effect when the confounding factor of spatial location of response associated with response hand was excluded. For this purpose, the assignment of response hand was changed from that used in Experiment 1A.

Materials and Methods

Participants

Sixty-eight Italian students (51 females; mean age= 26.01 years; SD= 4.40 years) were recruited for participation in an online study in exchange for course credits. According to the EHI (Oldfield, 1971), 58 were right-handed (M = 71.41; SD = 19.82) and 10 were left-handed (M = -62.41; SD = 31.74). Data from 8 participants (6 females) were not included because their performance accuracy was on average equal to 39.79%, which was lower than that of the participants who were included, the latter showing on average a performance accuracy of 93.36% ($t(66) = -11.89$; $p=.0001$) Thus, the data were based on the remaining 60 participants (47 females; mean age = 25.88 years; SD = 4.13 years; 52 right-handed). All participants had normal or corrected-to-normal vision and were not informed as 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.

Procedure and Data Analysis

The stimuli and experimental procedure were the same as those used for Experiment 1A, except for the response hand assignment. Specifically, participants had to press the “down” key with the right hand and the “up” key with the left hand in each block. 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 7%). At the end of the experimental procedure, participants answered the same question as before regarding their experimental perception of the response keys. The definitions of outliers and statistical analyses were identical to those adopted in Experiment 1.

Results

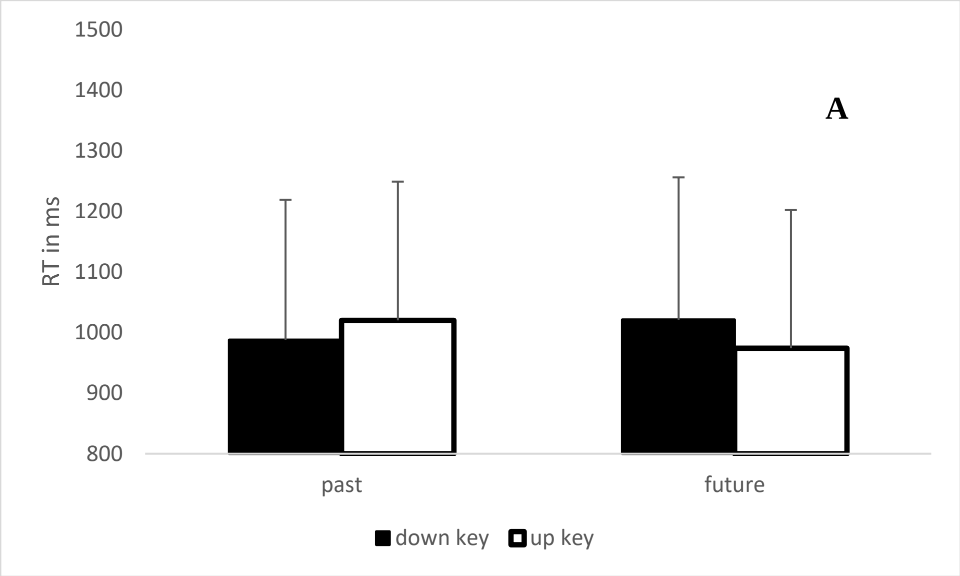
All descriptive data for RTs and accuracy (with their relative standard deviations or SDs) are displayed in Figure 2.

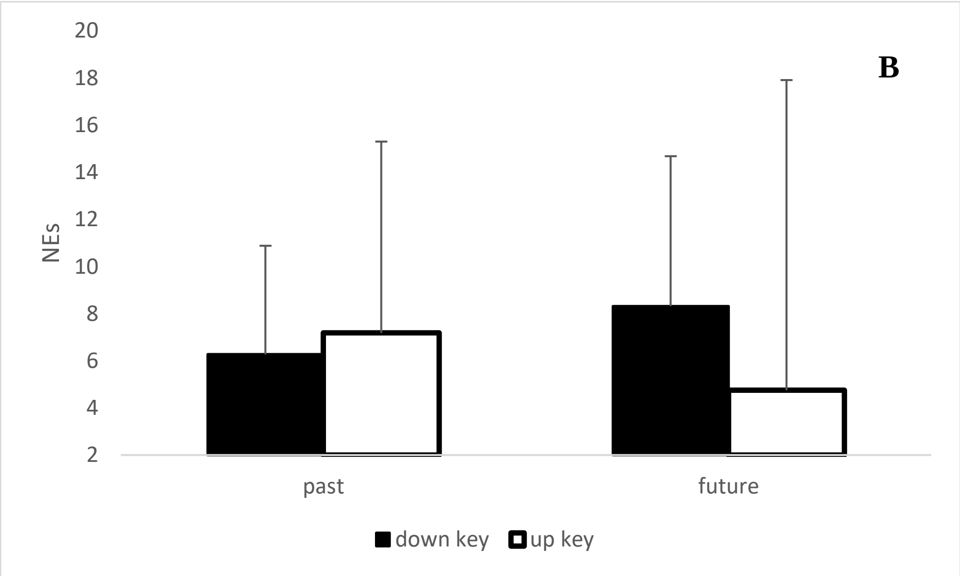
The Temporal Expression x Response Position ANOVA on RTs[4] revealed no significant main effects (all Fs < 0.77 with ps > .38, $\eta^2_{ps} < 0.01$) but a significant Temporal Expression x Response Position interaction ($F(1, 59) = 5.43$, $p < .05$, $\eta^2_p = 0.08$) was found, suggesting a clear congruency effect between past/future time and the response position. As displayed in Figure 2a, participants responded faster with the “down” key for temporal words referring to the past than with the “up” key, and provided faster responses with the “up” key for future words than with the

[4] The Temporal Expression x Response Position ANOVA on RTs was also performed on the total sample (N=68). Results showed neither significant main effects (all Fs < 2.20 with ps > 0.14, $\eta^2 p$s < 0.03) nor significant interactions ($F(1, 67) = 3.68$, $p = 0.06$, $\eta^2 p = 0.05$).

"down" key with $p < .05$ for all comparisons, suggesting a time representation from bottom-to-top on a MTL.

The same ANOVA on NEs[5], showed no significant main effects (all *F*s < 1.46 with *p*s > .23, $\eta^2_{ps} < 0.02$) but did show a significant Temporal Expression x Response Position interaction ($F(1, 59) = 5.41$, $p < .05$, $\eta^2_p = 0.08$). As displayed in Figure 2b, there were fewer NEs when participants judged the past expressions with the "down" key than with the "up" key; the same was true when they judged the future expressions with the "up" key rather than with the "down" key.





[5] The same ANOVA on NEs performed on the total sample (N=68) showed no significant main effects (all *F*s < 1.77 with *p*s > 0.19, $\eta^2 ps < 0.03$), but a Temporal Expression x Response Position interaction that tended to significance ($F(1, 67) = 3.88$, $p = .05$, $\eta^2 p = 0.05$) was observed. Participants performed fewer errors with the "down" key (M=9.62; SD=13.76) than with the "up" key (M=12.61; SD=19.44) for past expressions and with the "up" key (M=7.08; SD=16.57) than with the "down" key (M=12.71; SD=17.80) for future expressions.

Figure 2. A) the mean RTs for past and future expressions judged with the down key (black histogram) and up key (white histogram) for Experiment 1b; **B)** the mean NEs for past and future expressions judged with the down key (black histogram) and up key (white histogram) for Experiment 1b. In both figures, the bars represent SD.

Furthermore, the comparison between the dRT Past (M = -32 ms; SD = 141 ms) and dRT Future (M = -47 ms; SD = 150 ms) showed no differences between the two congruency effects $t(59) = 0.89$ $p = 0.38$, Cohen's $d = 0.10$.

As regards the ad-hoc question[6], 63% of participants perceived the arrow keys vertically (definitely or more vertically), 20% perceived the arrows as vertical and radial, and 17% of participants perceived the arrows as more radial or definitely radial.

Discussion

The aim of Experiment 1B was to rule out the possibility that the response hand assignment was a confounding factor for the interpretation of the results reported in Experiment 1A; to this end, we tested for the spatial reference frames involved in the vertical STEARC effect.

When changing the hand used to press the response keys (left hand for the "up" key and right hand for the "down" key), the results showed, once again, a clear vertical space-time association with faster responses and fewer errors for past expressions with the "down" key and for future expressions with the "up" key, in line with the "more is up" metaphor (Lakoff, 1987; Santiago et al., 2011). This finding could be in line with the literature reported for the SNARC effect, indicating that numbers and time are mapped to a spatial reference frame that is external to the body (Beracci et al., 2021b; Müller & Schwarz, 2007; Viarouge et al., 2014).

Based on our results, we confirmed a vertical time representation from bottom-to-top, even if we observed a smaller size effect, probable due to the change in hand assignment. In addition, the majority (63%) of our participants perceived the response keys as vertical in the study during the post-experiment question. Thus, we suggest that the vertical STEARC effect found in Experiment 1 was based primarily on the "sense of verticality" provided by the down/up arrows, in addition to the temporal stimuli used. However, we could not rule out the possibility that the similar results obtained in Experiments 1a and 1b could simply reflect a lack of compliance with the intended hand

[6] When all participants were considered, 62% of participants selected option 1 (definitely vertically) or 2 (more vertically than radially), 22% selected option 3 (it was indifferent), and 16% of participants selected option 4 (more radially than vertically) or 5 (definitely radially).

manipulation, given that we did not check that the participants followed this instruction during the execution of the online experiment. In addition, these findings needed to be replicated with a literal concept of verticality by displaying the response buttons vertically (i.e., without possible confounding radial/sagittal and vertical spaces). The aim of Experiment 2 was to test this replication.

Experiment 2

The aim of Experiment 2 was to confirm the vertical STEARC effect found in previous experiments, considering a literal concept of the term "vertical" in a 3-D context in which the response buttons were displayed vertically without any confounding down/near and up/far responses. Thus, the experimental procedure was the same as that of Experiments 1A and 1B, except for the fact that the response box was an external device positioned vertically, with bottom and top response keys along the vertical dimension. Subsequently, we required participants to place all the temporal expressions along a line (for a similar methodology see Woodin and Winter, 2018; see also Leone et al., 2018; Tversky et al., 1991), in order to disentangle the way in which temporal expressions were represented and confirm the findings of a speeded judgment task. Indeed, we used a set of temporal expressions without a specific order along a possible MTL and, thus, it was possible for participants to categorize each expression as related to the past or to the future. In this case, in the Time-To-Position task we expected to find all past expressions placed at the lower end compared to the middle of the line, whereas all future expressions would probably be placed on the upper part, above the middle of the line (i.e., the STEARC effect found in bimanual speeded responses). In both cases, no spatial sequence of past and future expressions was expected. However, the SPoARC effect might predict that not only would all past/future expressions be on the lower/upper side, but also, they would display a specific order. For example, the stimulus "in the past" (in Italian "in passato") could be positioned before "yesterday" (in Italian "ieri), because the former expression refers to a remote past while the latter expression refers to a closer past; in the same way, the stimulus "in the future" (in Italian "in futuro") could be positioned after "tomorrow" (in Italian "domani") because of references to different periods in the future. Thus, the temporal expression used here could provide not only past/future temporal information but also a probable sequential order with a specific spatial organization. Indeed, Beracci et al. (2021a) found that the temporal past/future expressions could be linearly displayed along a horizontal line with a specific order. In our opinion, the Time-To-Position task should clarify this aspect, providing further insight into the STEARC effect. For instance, a SPoARC-like effect in our Time-To-Position task would indicate not only that the STEARC effect arises from the past-lower and future-upper associations but would also suggest the involvement of a spatialization of temporal expressions along a vertical line. Finally, this task could explain the contrasting results reported by Woodin and Winter (2018; Tversky et al., 1991) or Leone et al. (2018), who used the same methodology. In our Time-To-Position task, participants placed all temporal expressions along a vertical line instead of on a page/screen in which both cardinal axes are presented. Thus, the Time-to-Position task might be able to verify the bottom-to-top mapping of the MTL and the existence of a probable temporal order of the stimuli along the line, leaving participants free to express their own representation vertically, without necessarily having to choose between two response keys.

Materials and Methods

Participants

Twenty-five[7] Italian students (21 females; mean age = 24.24 years; SD = 2.13 years) were recruited for participation in exchange for course credits. Based on their EHI (Oldfield, 1971) scores, all participants were right-handed (M = 85.25; SD = 17.41). All participants had normal or corrected-to-normal vision and were not informed as 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

All participants were individually tested in a quiet room. Stimulus presentation and data collection were controlled using E-Prime 2.0 (Schneider et al., 2002). All stimuli (the same as in the previous experiments) were presented on the dark background of a laptop computer screen. The display had a resolution of 1,072 × 960 pixels and was refreshed at a rate of 72 Hz.

Procedure

The experimental procedure was the same as that of Experiments 1A and 1B, with the exception of the response device. Participants were required to categorize the 20 target expressions as referring to the past or to the future, using a response box (Cedrus RB-x40 Response Pads) connected to a laptop using a universal serial bus (USB), positioned vertically (see Figure 3). They were instructed to press one of two vertical buttons: a yellow key positioned at the bottom, with the left hand and a blue key, at the top of the response box, with the right hand. The task was performed twice, using two different blocks, in which the instruction–key assignments were counterbalanced. In one block, the yellow key (or lower key) was pressed in order to categorize the past, and the blue key (or upper key) to categorize the future. In the other block, the yellow key (or lower key) was

[7] The sample size in Experiment 2 was smaller compared to the previous experiments because this experiment required laboratory administration for the use of the vertical response box. Unfortunately, data collection was interrupted by the worldwide COVID-19 pandemic emergency. Nevertheless, this sample size remained in line with the result of the power analysis (N = 12 individuals for within-group comparison: with an alpha = .05 and power = .80).

pressed in order to categorize the future temporal expressions, and the blue key (or upper key) to categorize the past temporal expressions. The order of blocks was counterbalanced within participants.

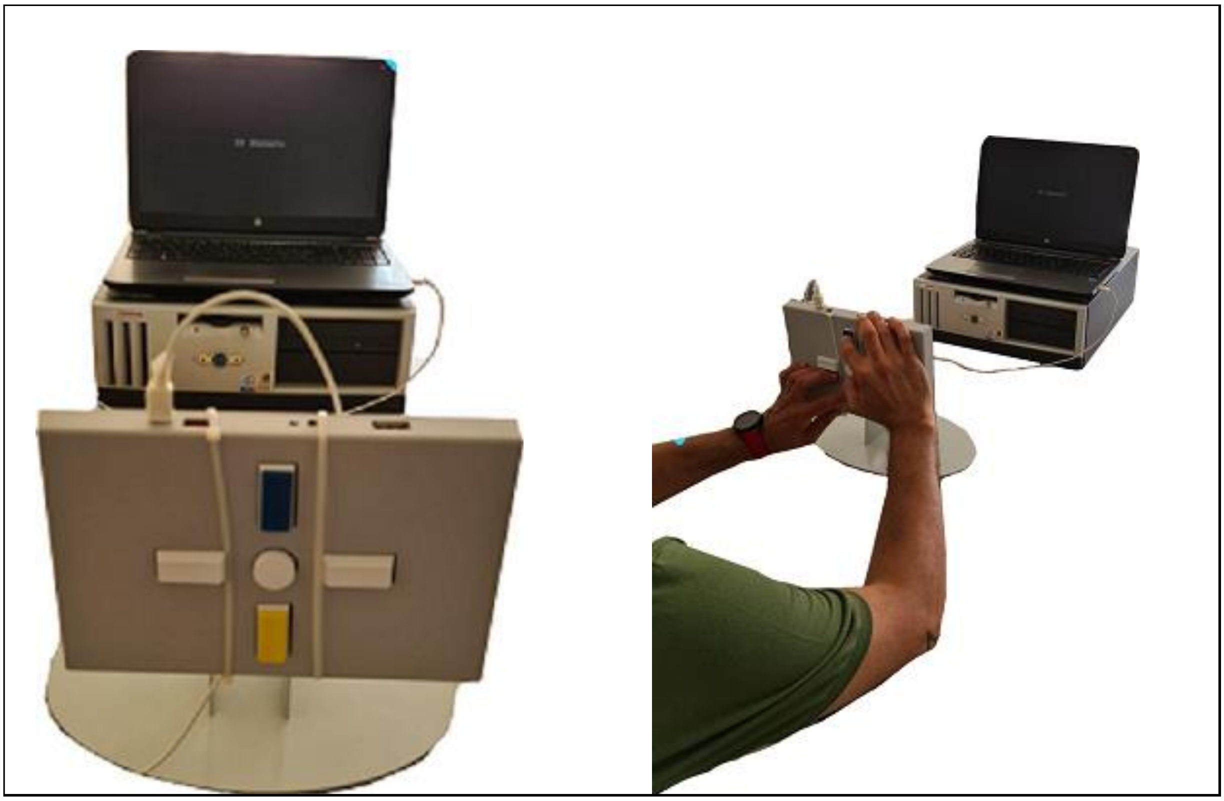


Figure 3. On the left side of the figure, the vertical disposition of the response box (Cedrus RB-x40 Response Pads) used in the study. Participants had to press one of two vertical buttons: a yellow key positioned at the bottom, with the left hand and a blue key, at the top of the response box, with the right hand, as displayed on the right side of the figure.

At the end of these tasks, participants were requested to perform a Time-To-Position task, in which they placed all 20 temporal expressions along 10cm-long lines flanked by two labels "*passato lontano*" ("distant past" in English) at the bottom and "*futuro lontano*" ("distant future" in English) at the top. The 20 temporal expressions were written near the top of the page (i.e., above the vertical line centrally on the page). Trials were presented in sets of four lines per page (for a total of five sheets of white A4 paper) in different positions on the page. In order to avoid participants being influenced by previous positioning, we created a mask that covered three of the target lines in order to make participants focus on a single line. The order of the temporal expressions was completely randomized. Participants had to decide where the temporal expression should be positioned on the line and make a vertical mark with their pencil (see Fabbri & Guarini, 2016, Fabbri & Natale, 2016, for a similar procedure adopted with numbers). In a similar way to the horizontal Number-to-Position task (Ebersbach, Luwel, Frich, Onghena & Verschaffel, 2008; Fabbri & Guarini, 2016; Fabbri & Natale, 2016; Siegler & Opfer, 2003), we measured the distance (in millimeters) from the bottom of the line to the subjective mark positioned on the line for each participant and for each temporal expression. Thus, the lower (bottom) space was defined by all values before (below) 50 mms while the upper (top) space was defined by all values after (above) 50 mms.

Data Analysis

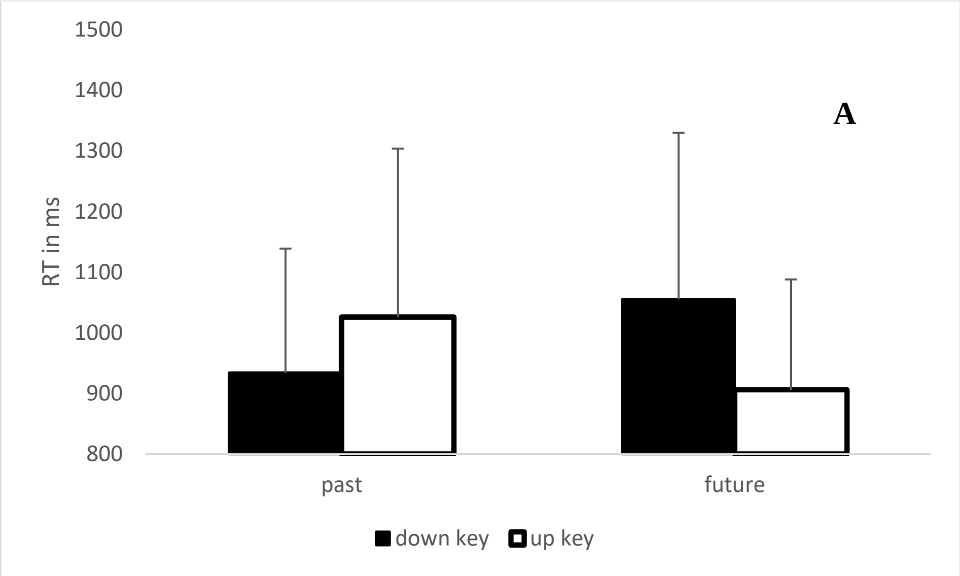
As in Experiments 1A and 1B, the mean reaction times (RTs) of correct responses were calculated using the software SPSS version 20.0 (IBM Corp.) To improve the internal validity of the study, RTs more than 3 SDs above or below the mean were discarded as outliers (about 6%). A two-way repeated measures ANOVA was carried out on RTs and NEs, with Temporal Expression (past vs. future) x Response Position (bottom key vs. top key) as within-subjects factors. Subsequently, we performed a within-subjects t-test, in order to compare the congruency effects, separately for past (dRT Past= RT down key – RT top key) and future (dRT Future= RT top key – RT down key). For the Time-To-Position task, we tested the presence of a linear fit (R^2).

Results

All descriptive data for RTs and accuracy (with their relative standard deviations or SDs) are displayed in Figure 4.

The Temporal Expression x Response Position ANOVA on RTs revealed no significant main effect for Temporal Expression ($F(1, 24) = 0.003$, $p = .96$, $\eta^2_p = 0.001$), but a significant main effect for Response Position ($F(1, 24) = 7.17$, $p < .05$, $\eta^2_p = 0.23$) was present, with faster responses for the top key (M = 966 ms; SD = 231 ms) than for the bottom key (M = 996 ms; SD = 240 ms). There was also a significant Temporal Expression x Response Position interaction ($F(1, 24) = 14.56$, $p < .005$, $\eta^2_p = 0.38$), suggesting faster responses with the bottom key for temporal words referring to the past than with the top key, whereas faster responses were evident when the top key was used for future words than when the bottom key was used, with $p < .05$ for all comparisons, as displayed in Figure 4a.

The same ANOVA on NEs showed neither significant main effects (all *F*s < 0.11 with *p*s > .74, $\eta^2_{ps} < 0.01$) nor significant interactions ($F(1, 24) = 1.83$, $p = 0.19$, $\eta^2_p = 0.07$), as shown in Figure 4b.



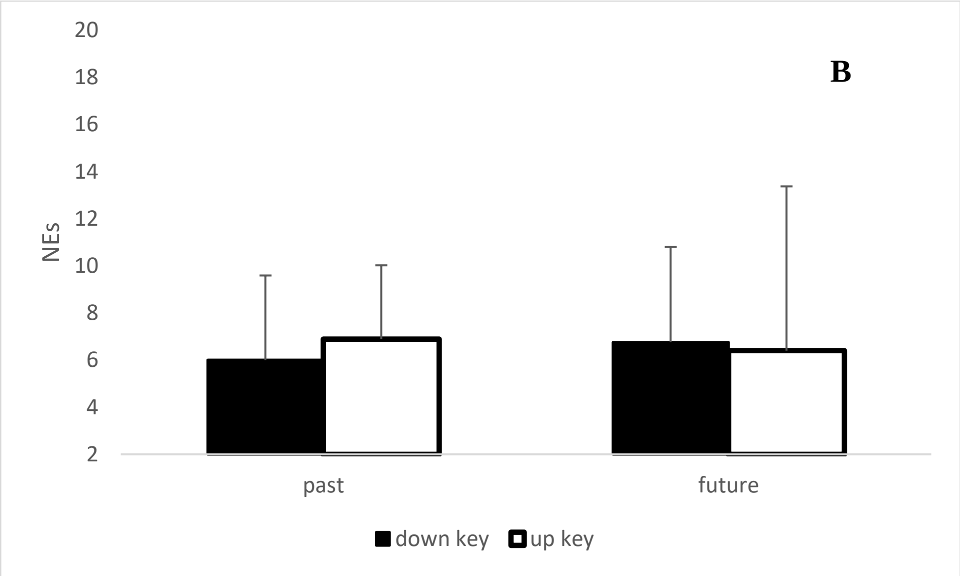


Figure 4. A) the mean RTs for past and future expressions judged with the down key (black histogram) and up key (white histogram) for Experiment 2; **B)** the mean NEs for past and future expressions judged with the down key (black histogram) and up key (white histogram) for Experiment 2. In both figures, the bars represent SD.

Moreover, the comparison between the dRT Past (M = -93 ms; SD = 159 ms) and dRT Future (M = -149 ms; SD = 175 ms) showed a difference between the two congruency effects $t(24) = 2.68$ $p < .05$, Cohen's $d = 0.34$), indicating a larger congruency effect for future expressions.

Time-To-Position Task

As shown in Figure 5, Italian speakers placed the 20 temporal expressions in an ordered pattern from bottom-to-top along a linear timeline. In this way, with participants free to express their own representation vertically, the results showed a clear vertical time representation (linear fit model: R^2 = 0.831; SD = 0.09; $t(24)$ = 44.83, p = .001, Cohen's d = 9.23).

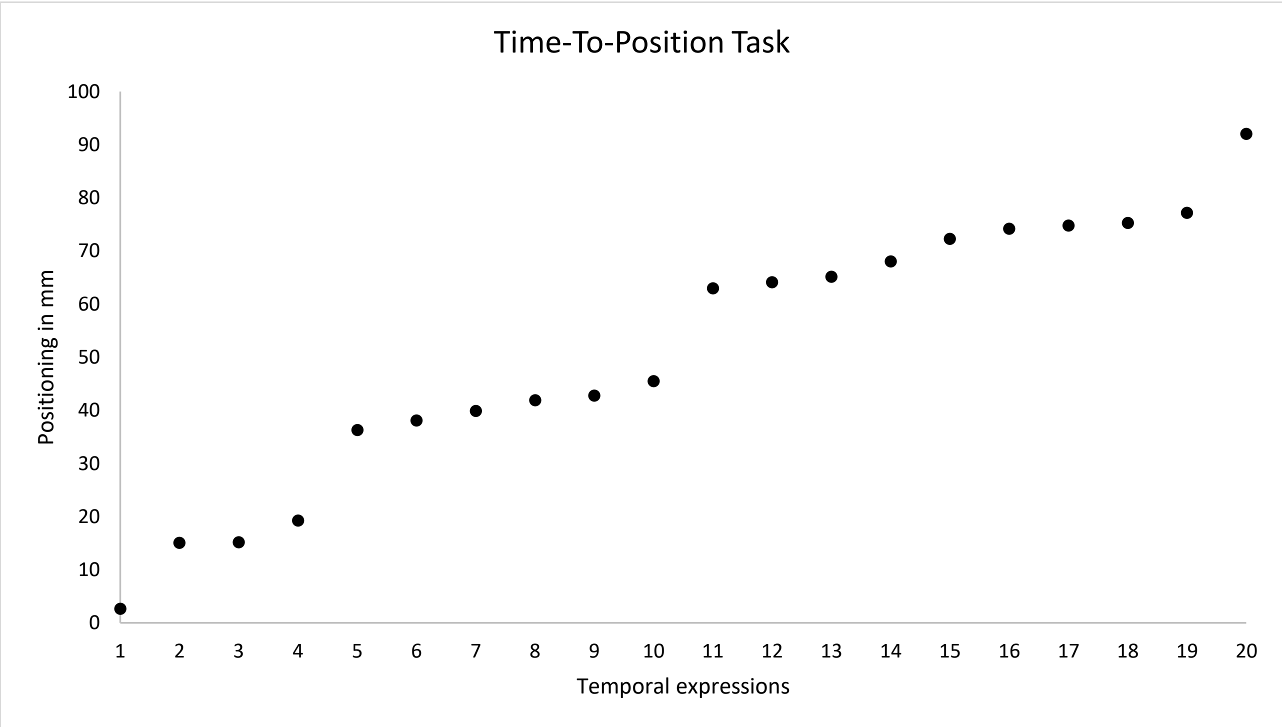


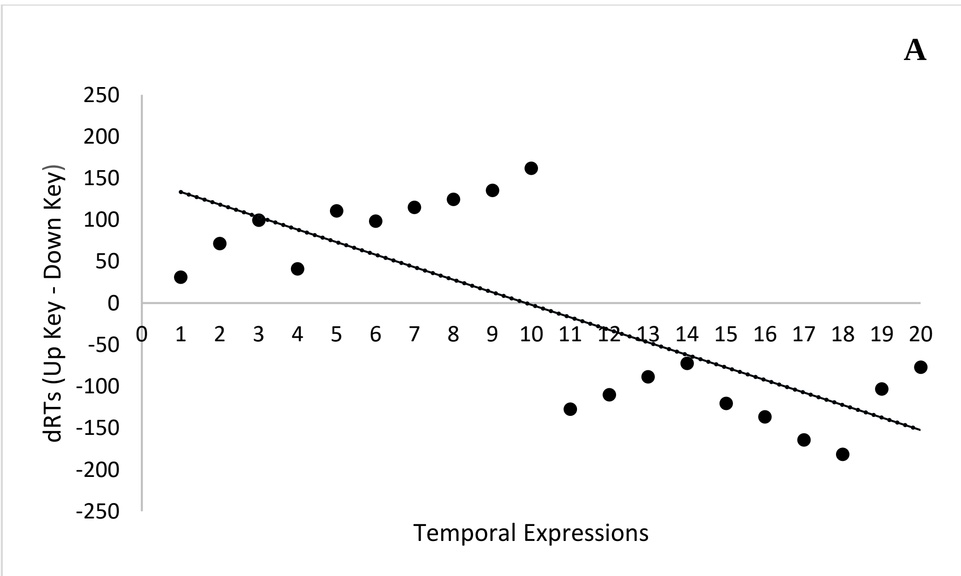
Figure 5. Distance of each temporal expression from the bottom of the line and subjective mark positioned on the line in millimeters (mm).

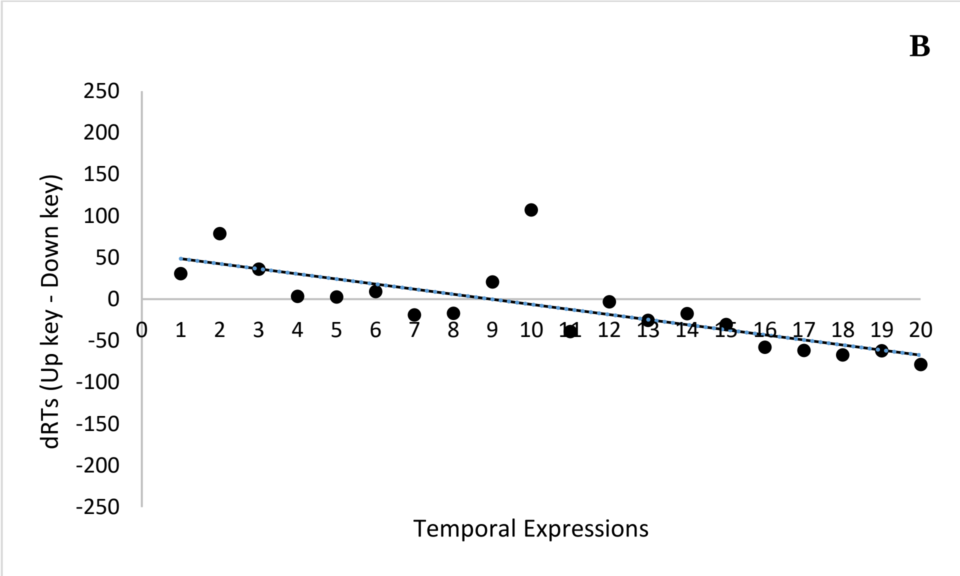
Note. Items: 1 = Anticamente, 2 = Tempo fa, 3 = In passato, 4 = Una volta, 5= Precedentemente, 6 = L'altro ieri, 7 = L'altro giorno, 8 = Prima, 9 = Ieri, 10 = Recentemente, 11 = Dopo, 12 = Tra poco, 13 = Presto, 14 = Conseguentemente, 15 = Domani, 16 = In seguito, 17 = Dopodomani, 18 = Successivamente, 19 = Prossimamente, 20 = In futuro. For a translation of Italian expressions see the Appendix.

STEARC Effect

In order to analyse the STEARC effect in a similar way to the SNARC effect (e.g., Dehaene et al., 1993), as well as to determine the direction and the strength of the space-time congruency effect, we performed the regression analysis described by Lorch and Myers (1990) for each experiment. For each participant and each temporal expression, the average difference (dRT) between RT "up" and RT "down" keys was calculated. This score was then regressed on superimposed temporal expression order (defined by the results of the Time-To-Position task), yielding a non-standardized regression weight for each participant which captured the direction and strength of the spatial mapping of time concepts. A negative slope showed that the sequence of the temporal target proceeded upward. These slope coefficients were tested against zero within by means of a one-tailed t-test.

The results showed that all the slope coefficients were significantly different from zero: Experiment 1A (b = -15.43; SD = 31.17; $t(85) = -4.59$, $p < .0001$, Cohen's $d = -0.50$), Experiment 1B (b = -7.43; SD = 19.43; $t(59) = -2.96$, $p < .005$, Cohen's $d = -0.38$) and Experiment 2 (b = -16.90; SD = 22.16; $t(24) = -3.81$, $p < .005$, Cohen's $d = -0.76$), suggesting a bottom-to-top mental time representation of the 20 temporal words (see Figure 6, 6a, 6b, and 6c, respectively). Additionally, a one-way ANOVA with the between-subject factor Experiment (1A, 1B, 2) was performed on the coefficient slopes (b). The results did not show a significant effect ($F(2,168) = 2.10$, $p = .13$, $\eta^2_p = 0.02$), confirming that there is no difference between the STEARC effects found in the three Experiments.





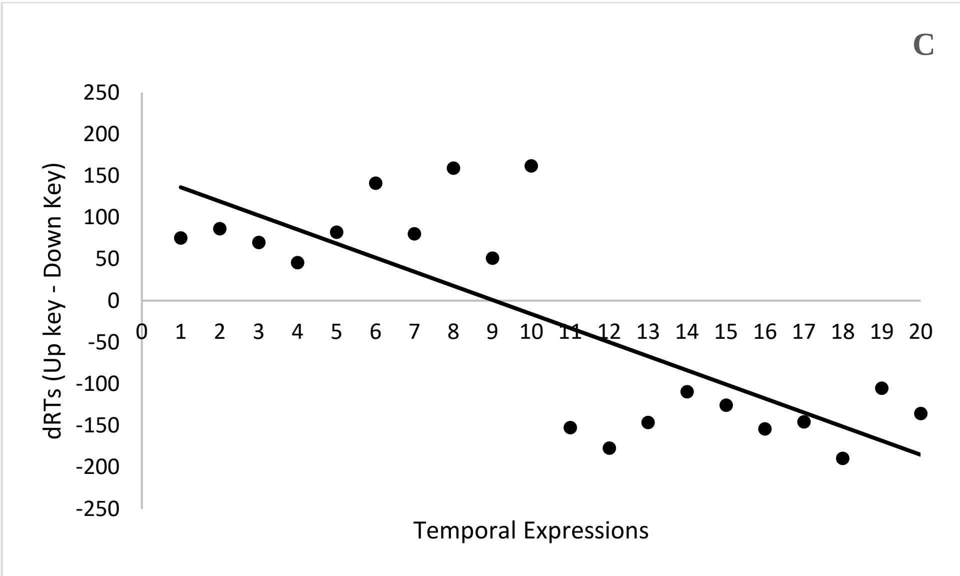


Figure 6. **a)** Mean dRTs (up key – down key) in Experiment 1A for each target expression (numbers 1 to 20; see legend) with the specific order sequence found in the time-to-position task ; **b)** Mean dRTs (up key – down key) in Experiment 1B for each target expression (numbers 1 to 20; see legend) with the specific order sequence found in the time-to-position task ; **c)** Mean dRTs (up key – down key) in Experiment 2 for each target expression (numbers 1 to 20; see legend) with the specific order sequence found in the time-to-position task .

Note. Legend: 1 = Anticamente, 2 = Tempo fa, 3 = In passato, 4 = Una volta, 5= Precedentemente, 6 = L'altro ieri, 7 = L'altro giorno, 8 = Prima, 9 = Ieri, 10 = Recentemente, 11 = Dopo, 12 = Tra poco, 13 = Presto, 14 = Conseguentemente, 15 = Domani, 16 = In seguito, 17 = Dopodomani, 18 = Successivamente, 19 = Prossimamente, 20 = In futuro

Discussion

The aim of Experiment 2 was to confirm a vertical bottom-to-top space-time association when executing a literal concept of the term "vertical", provided by a response box positioned vertically. We found the same results as those obtained when an analogous representation of "verticality" was used in previous experiments. Altogether, these findings suggest that the response mapping supporting a vertical dimension (e.g., an up arrow or a key placed higher in vertical space) could induce a bottom-to-top representation of time. In other words, in the present experiment (and in the previous ones) the finding of a vertical STEARC effect suggests an association between the past and the bottom key and between the future and the top key, showing a vertical MTL oriented from bottom-to-top, as predicted by the "more is up" metaphor (Lakoff & Johnson, 1980, 1999). In addition, in the Time-To-Position task (when participants were free to place temporal expressions along the line), we found not only that all past expressions were below and all future expressions were above the middle of the lines (confirming the STEARC effect of the speeded task), but also an ordered vertical pattern, with a linearity fit from "formerly" (i.e, *anticamente*) to "in the future" (i.e., *in future*). This result could be due to the fact that the temporal expressions used in the study are used daily to refer to events in different past/future positions, suggesting a temporal progression in the mind (a sort of mental time travel), with a specific order on a line. This finding could suggest that the vertical STEARC effect found derived, not only from the associations between past expressions and the down key/space, and between future expressions and the up key/space, but also from a possible presence of a sequential order of temporal stimuli, validating a SPoARC-like effect (Abrahamse et al., 2014; Beracci et al., 2021a; Ginsburg et al., 2014; Zhou et al., 2019). Thus, the vertical STEARC effect, found in the temporal judgment task, and, especially, the ordinal position of the temporal expressions along the vertical line, could derive from the position effect as proposed by van Dijck and Fias (2011) as an explanation of the SNARC effect. In other words, it is possible to speculate that, in the Time-To-Position task, our participants represented and maintained each spatial position of every temporal expression in their working memory (Abrahmse et al., 2014), due to the randomization of stimuli presentation and the use of mask which obliged them to focus on a single temporal expression (and a single vertical line) at a time.

However, the results in the Time-To-Position task could be influenced by the fact that this task was performed after the temporal judgment task, with the risk that the positions of expressions on the line depended on demand characteristics imposed by the bimanual response task, and by the flankers at both edges of the line determining spatial biases. In our opinion, these aspects do not explain the result pattern reported in Figure 5 because we adopted a series of methodological details to limit these influences. Indeed, all temporal expressions were presented in the upper position of the page (above the vertical line), the lines were positioned in different spaces on the page, a mask covered all the lines printed on the page, leaving only one line visible at a time, and the order of the temporal expressions was randomized (see also Beracci et al., 2021a for similar methodological constraints with horizontal lines). Taking into account that Woodin and Winter (2018) as well as Leone et al. (2018) allowed participants to place all elements on a single page (on which both cardinal axes were presented) or on a screen/canvas, with the possibility that not only could performance be influenced by the spatial position of each item in order but also by the spatial information provided by the axes/screen, we think that the methodology adopted in our Time-To-Position task should be sufficient to prevent the above-acknowledged limits.

Finally, when we calculated the strength and the direction of the STEARC effect using the order of expression found in the Time-To-Position task for each experiment, we did not find any statistical differences, suggesting the similarity of our STEARC effects through the different experimental manipulations. It is possible that this similarity not only confirms, but also extends, the spatial-temporal association in all temporal concepts (D-time, S-time and T-span; Núñez & Cooperrider, 2013). These similar results across different experiments could indicate that the vertical space-time association is in line with the conceptual metaphor "more is up" (Lakoff, 1987), with the addition of spatial information provided by the ordered sequence (Zhou et al., 2019). In addition, these findings suggest that a similar STEARC effect could be obtained using an analogous (2-D) or literal (3-D) concept of the term vertical, proposing a possible solution for the debate regarding the comparison between radial and vertical response buttons.

General Discussion

The purpose of our study was to determine a vertical space-time association, and specifically the direction of this vertical representation, given that in the literature no definitive conclusion has been reported. Indeed, several studies failed to report any vertical STEARC effect (Casasanto & Bottini, 2013; Hartmann & Mast, 2012; Ishihara et al., 2008; Kolesari & Carlson, 2018; Miles et al., 2011), while other studies showed either a bottom-to-top (Beracci et al., 2021b; Leone et al., 2018; Ruiz-Fernandéz et al., 2014), or a top-to-bottom direction of temporal representation (Boroditsky, 2001; He et al., 2018; Topić et al., 2021). To reach our purpose, we attempted to overcome several methodological issues, such as the temporal stimuli used (in the current study, we presented 20 Italian temporal expressions referring to the past or the future), the concept (analogous and literal) of verticality, the hand used to respond and a consequent assessment of the spatial reference frames (i.e., testing extracorporeal spatial information and anatomical information) of the STEARC effect, and the comparison between a speeded bimanual task and a free positional (Time-To-Position) task.

In all experiments, the results were very clear. We showed a STEARC effect, with an association between the past and the bottom key and the future and the top key (Beracci et al., 2021b; Leone et al., 2018; Ruiz-Fernandéz et al., 2014), in line with the "more is up" metaphor (Lakoff, 1987; Lakoff & Johnson, 1980, 1999). In line with the grounded theory (see also TEST model; Myachykov et al., 2014), the conceptualization of abstract concepts along the vertical space is based on a concrete sensorimotor experience with the physical world. For instance, people have experience in daily life of the increasing of time, such as the growing process or the vertical arrangement of buildings from the ground floor to the attic (Santiago et al., 2011). It is possible to consider this assumption as a specific case of the CORE principle (Pitt & Casasanto, 2020), according to which different aspects of experience should selectively provide the association between space and time (Casasanto & Bottini, 2013). Taking into account that Pitt and Casasanto (2020) were focused on the horizontal MTL (with a specific influence of reading experience), we proposed that the vertical experience, for example, of an elevator could provide the bottom-to-top representation of time. This assumption could be based on the fact that our participants were all Italian and the main reading experience in Italian culture (as in Western culture) is in a top-to-bottom direction, and on the fact that there are linguistic time expressions along the vertical axis (Lakoff & Johnson, 1980). In our opinion, the "more is up" metaphor is the account that best explains our vertical STEARC, considering that Santiago and Lakens (2015; see also Di Rosa et al., 2017; Leth-Steensen & Citta, 2016) challenged the efficacy of the polarity correspondence (Proctor & Cho, 2006) in explaining SNARC-like effects. Although the ATOM model (Bueto & Walsh, 2009; Fabbri et al., 2012; Walsh, 2003, 2015) could predict small-bottom and large-top associations, we do not think that this framework accounts for our results because the temporal stimuli used in the present study were not quantities (e.g., temporal durations; Beracci et al., 2021b), which are the main core of the ATOM model. In addition, the methodological considerations adopted in the present study should exclude this alternative explanation, as discussed in the following paragraphs.

As regards the response setting, we used the directional arrows ("down" and "up" arrows) as response keys (Experiments 1a, 1b), or we placed the response buttons vertically (Experiment 2). These choices probably activated the vertical dimension in a stronger and more direct way compared to when two response buttons of a computer keyboard were arranged along the vertical axis (Casasanto & Bottini, 2013; Hartmann & Mast, 2012; Kolesari & Carlson, 2018; Miles et al.,

2011) or when a search array was used (Topić et al., 2021). In a similar way, we found a spatial-temporal association along the vertical axis, when participants were free to place different temporal stimuli along a vertically-drawn line, increasing the possibility of adopting a vertical dimension in representing time, as opposed to a piece of A4 paper with a pair of central axes (or empty page), as presented by Woodin and Winter (2018). Altogether, it is possible to suggest that "external" features, such as vertical lines, vertical response keys, or vertical arrows might activate a vertical time representation (see Shaki & Fischer, 2018 for a similar account with numbers). In other words, the vertical arrows or down/up buttons could remind one of the daily life experience of pressing keys in the elevator, inducing the arrangement of time along the vertical axis, in a similar way to numbers (Aleotti et al., 2020).

As regards the materials used, all experiments showed that our temporal expressions may have induced a vertical STEARC effect, with the same orientation reported when temporal durations (in milliseconds) were used (Beracci et al., 2021b). As clearly shown in the Time-To-Position task (Figure 5), the temporal expressions were linearly displayed along the line from the bottom part (referring to the "distant past") to the top end of the line (referring to the "distant future"), in a similar way to all stimuli that show a temporal progression, such as "*Monday is before Wednesday*" (Bergen & Chan Lau, 2012; Chen, 2007; Fuhrman & Boroditsky, 2010). Thus, past/future expressions (earlier or later than the present) seemed to induce a clear vertical STEARC effect than the time words used by Woodin and Winter (2018). Indeed, Leone et al. (2018) found that participants produced an ordered past-present-future sequence upward. In a similar way, words referring to the future induced a faster detection of a visual target positioned in the upper space and words that referred to the past induced a faster detection of a visual target positioned in the lower space (Ruiz Fernandéz et al., 2014). This leads us to conclude that, since these expressions are used on a daily basis in order to refer to the timing of different life events, they occupy specific positions on the temporal mental line, with a "specific order". Thus, in this experiment a MTL may have been involved to a greater extent than in previous studies which used fixed past-related and future-related verbal stimuli (Hartmann & Mast, 2012). This finding reflected a SPoARC-like effect, suggesting the influence of an ordinal position effect (Abrahamse et al., 2014, 2016; Ginsburg et al., 2014; van Dijck & Fias, 2011) as a possible additional explanation of the bottom-to-top time representation. The linear pattern of temporal expressions could suggest that the progressive ordered temporal arrangement of the temporal expressions could determine the spatial association between the past and the bottom part, as well as between the future and the top part of space (Zhou et al., 2019). In our opinion, both the "more is up" metaphor account and the SPoARC-like effect remain valid in the interpretation of our data, and they are not mutually exclusive. Indeed, Beracci et al. (2021a) demonstrated the presence of a continuous MTL for the horizontal STEARC effect, which could be used categorically when the task required an explicit temporal judgment task. Thus, the ordinality of the temporal expressions activated internal spatial attention, using spatial (vertical) coordinates, in line with the experience of verticality (see Abrahmse et al., 2014 with the mental whiteboard hypothesis). However, these considerations could be further investigated with an implicit task in a similar way to the horizontal STEARC effect (Di Bono et al., 2012).

The study was also calibrated in order to address a typical controversial debate regarding the concept of verticality. In all experiments, we systematically found a bottom-to-top STEARC effect, suggesting a similarity between analogous and literal concepts of verticality. Indeed, in both Experiment 1a and Experiment 1b, we found that the down arrow was associated with the past and the up arrow was associated with the future. Although this result could be discussed as a radial (near/far) STEARC effect, we further confirmed these associations when response buttons were vertically arranged (without any possible confounding association between down/near and up/far) in Experiment 2. Taking into account the linear regression analyses (Figure 6), we advanced the idea that we obtained a "unique" vertical STEARC effect, with an analogous and literal concept of verticality. Indeed, we did not find differences between the slope coefficients of all experiments, suggesting that a vertical representation of abstract concepts could be studied with keys placed above and below, even if displayed in a horizontal keyboard. This suggestion was also based on the responses to the debriefing questions reported by participants. Indeed, the majority of participants in both Experiments 1a and 1b perceived the up arrow as the top key and the down arrow as the bottom key.

Additional evidence that emerged from the present study was related to the extracorporeal spatial information for the vertical STEARC effect. The possible confounding effect between the spatial location of response keys and the hand used to respond is an interesting methodological issue, that has not always been controlled for (Ishihara et al., 2008; Miles et al., 2011). Regarding this issue, our results are in line with those of Ito and Hatta (2004) who performed two experiments with numbers, with the participant's left hand assigned to the bottom key and the right hand to the top key, as well as with an opposite assignment of response hand; similar results emerged for both experiments, suggesting that number magnitude was associated with the vertical position of response but not with the response hands (see also Shaki & Fischer, 2012). In both Experiments 1a and 1b, the vertical STEARC effect observed did not depend on the hand used, because the results did not change with an opposite response hand assignment. This result suggests that the extracorporal hypothesis could account for the vertical STEARC effect. In other words, this finding indicates that the activation of the time representation was space-related, independently from the specific effector system used, in line with the extracorporeal (location) hypothesis (see Müller & Schwarz, 2007, Schwarz & Keus, 2004, and Viarouge et al., 2014 for a similar discussion in the numerical domain). However, Müller and Schwarz (2007) found that, with vertically-arranged buttons, numbers were not only represented in terms of extracorporeal space (spatial position of buttons with respect to the body) but also related to the specific spatial representation of hands on the basis of the task setting/instruction created. Future studies should address this possibility in the temporal domain.

In summary, participants performed a classic temporal task, judging 20 Italian temporal expressions as referring to the past or the future (temporal order), considering both the analogous (using the “down”/”up” arrows on a standard keyboard) and the literal concept of “verticality” (using a vertically-positioned response box). In both experiments, we obtained a vertical space-time congruency effect, with an association between the past and bottom space and between the future and top space. This vertical mapping found was task-dependent and was influenced by the experimental manipulation (for a similar explanation, see Shaki & Fischer, 2018). In addition, we further confirmed these spatial-temporal associations using a Time-To-Position task, in which participants were free to place the temporal expressions along a vertical line. Thus, we can assume the presence of a bottom-to-top vertical space-time association, probably suggesting that our daily life experiences in the physical world influence our temporal domain representation, according to the metaphor “more is up”. This assumption is in line with the findings reported along the vertical space for temporal duration (Beracci et al., 2021b).

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Appendix

Temporal Expressions

Table A1

Italians Temporal Expressions (With Their Translations in Brackets) Used as Stimuli of the Study

Number Expression	Materials (translation in brackets)
	PAST
1	*Anticamente* (formerly)
2	*Tempo fa* (long ago)
3	*In passato* (in the past)
4	*Una volta* (once)
5	*Precedentemente* (previously)
6	*L'altro ieri* (the day before yesterday)
7	*L'altro giorno* (the other day)
8	*Prima* (before)
9	*Ieri* (yesterday)
10	*Recentemente* (recently)
	FUTURE
11	*Dopo* (after)
12	*Tra poco* (soon)
13	*Presto* (early)
14	*Conseguentemente* (consequently)
15	*Domani* (tomorrow)
16	*In seguito* (later)
17	*Dopodomani* (the day after tomorrow)
18	*Successivamente* (subsequently)
19	*Prossimamente* (next)
20	*In futuro* (in the future)