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The Vertical Space-Time Association

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ABSTRACT

The space-time interaction suggests a left-to-right directionality in the mind's representation of elapsing time. However, studies showing a possible vertical time representation are scarce and contradictory. In Experiment 1, 32 participants had to judge the duration (200, 300, 500 or 600 milliseconds) of the target stimulus that appeared at the top, centre, or bottom of the screen, compared to a reference stimulus (400 milliseconds) always appeared in the centre of the screen. In Experiment 2, 32 participants were administered with the same procedure, but the reference stimulus appeared at the top, centre, or bottom of the screen and the target stimulus was fixed in the centre location. In both experiments, a space-time interaction was found with an association between short durations and bottom response key as well as between long durations and top key. The evidence of a vertical mental timeline was further confirmed by the distance effect with a lower level of performance for durations close to that of the reference stimulus. The results suggest a bottom-to-top mapping of time representation, more in line with the metaphor "*more is up*".

Keywords: STEARC effect; Vertical Dimension; More Is Up Metaphor; Embodied Cognition; Temporal Duration Task

1. INTRODUCTION

It has been extensively documented that numbers are automatically mapped onto space in our minds (Fabbri & Guarini, 2016; Macnamara. Keage, & Loetscher, 2018; Winter, Marghetis, & Matlock, 2015a; Wood, Willmes, Nuerk, & Fischer, 2008). Dehaene, Bossini and Giraux (1993) showed that Western participants made faster responses to smaller numbers (e.g., 1 or 2) when the response key was on the left and faster responses to larger numbers (e.g., 8 or 9) when the response key was on the right, suggesting the Spatial-Numerical Association of Response Codes (SNARC) effect. Thus, it has been argued that numbers are represented along a mental number line (MNL) oriented from left to right or from right to left, according to cultural reading and writing habits (Göbel, Shaki, & Fischer, 2011). Several lines of research have clearly demonstrated a SNARC-like effect (e.g., Kiesel & Vierck, 2009) for other non-numerical constructs, such as days of the week (Gevers, Reynvoet, & Fias, 2004), alphabetic letters and months of the year (Gevers, Reynvoet, & Fias, 2003), loudness (Bruzzi, Talamini, Priftis, & Grassi, 2017; Chang & Cho, 2015), luminance (Fumarola, Prpic, Da Pos, Murgia, Umiltà & Agostini, 2014), size (Sellaro, Treccani, Job & Cubelli, 2015) and weight (Dalmaso & Vicovaro, 2019). Thus, it has been suggested that a more appropriate term, such as Spatial-Quantity Association of Response Codes (SQUARC) effect, could be used to refer to a general mechanism for magnitude processing (Macnamara et al., 2018; Winter, Marghetis & Matlock, 2015b; Walsh, 2003, 2015). The SQUARC effect could be considered the manifestation of a more general mechanism devoted to the processing of magnitudes (Cohen Kadosh, Lammertyn, & Izard, 2008; Lourenco & Longo, 2010). Specifically, the A Theory Of Magnitude (ATOM, Bueti & Walsh, 2009; Walsh, 2003) advances the idea of a domain-general representation of magnitude with a common neural substrate that predicts associations between space, number and other quantities according to a general "*more A, more B*" rule. Further evidence of the existence of a shared magnitude representation is found when two other basic effects in numerical domains, such as the distance and size effects, are considered (Cohen Kadosh et al., 2008). The numerical distance effect (Moyer & Landauer, 1967) is reflected in a better performance in a magnitude comparison task when two numbers are quantitatively further away (e.g., 1 and 9) than when two numbers are quantitatively close to each other (e.g., 1 and 2). When the numerical distance is kept constant, the size effect (Moyer & Landauer, 1967) reflects a better performance when comparing two small numbers (e.g., 1 and 2) than when comparing two large numbers (e.g., 8 and 9). The distance effect has been observed with the size of geometrical shapes (Fulbright, Manson, Skudlarski, Lacadie, & Gore, 2003; Sellaro et al., 2015), luminance (Cohen Kadosh & Henik, 2006; Fumarola et al., 2014; Pinel, Piazza, Le Bihan, & Dehaene, 2004), pitch height (Bruzzi et al., 2017; Rusconi, Kwan, Giordano, Umiltà, & Butterworth, 2006), ordinal sequence of elements (i.e., days, alphabetic letters, and months; Gevers et al., 2003, 2004), and weight (Dalmasio & Vicario, 2019). At the same time, the size effect has been observed with pairs of angles or pairs of lines (Cohen Kadosh et al., 2008; Fias, Lammertyn, Reynvoet, Dupont, & Orban, 2003), even if a reversed size effect for loudness is found (Chang & Cho, 2015).

Another abstract concept that is coded by means of a more concrete domain, such as space, is time. A horizontal space-time interaction has recently been found, reflecting a Spatial-Temporal Association of Response Codes (STEARC) effect, suggesting that short durations are associated with the left side whereas longer durations are associated with the right side (Bonato, Zorzi, Umiltà, 2012; Winter et al., 2015a,b). Interestingly, this space-time interaction has been confirmed using different temporal materials, such as visual (Fabbri, Cancellieri & Natale, 2012; Fabbri, Cellini, Martoni, Tonetti, & Natale, 2013a,b; Vallesi, Binns, & Shallice, 2008; Vallesi, Weisblatt, Semenza, & Shaki, 2014) or auditory (Ishihara, Keller, Rossetti, & Prinz, 2008) stimuli lasting several milliseconds or seconds, temporal verbs or expressions to indicate event sequences (Bottini & Casasanto, 2013; Casasanto & Bottini, 2014a,b; Ouellet, Santiago, Funes, & Lupiáñez, 2010a; Ouellet, Santiago, Israeli, & Gabay, 2010b; Santiago, Lupiáñez, Pérez, & Funes, 2007; Torralbo, Santiago, & Lupiáñez, 2006), or the time of popularity of actors/actresses (i.e., popularity in the first half of the 20th century like Charlie Chaplin vs. current popularity like Brad Pitt), in relation to a reference moment (e.g., when participants were born; Weger & Pratt, 2008). Altogether these results suggest the idea that humans represent time in a spatially oriented mental timeline or MTL (Di Bono, Casarotti, Gava, Umiltà & Zorzi, 2012; Ishihara et al, 2008; Vallesi, McIntosh & Stuss, 2011), oriented from left to right or from right to left, according to cultural direction of reading and writing. (Casasanto & Bottini, 2014b; Chen, 2007; Fuhrman & Boroditsky, 2010; Tversky, Kugelmass, & Winter, 1991). Additional evidence of the MTL can be found in the distance effect in the duration comparison task, indicating that a temporal magnitude is accessed and placed on a MTL, after which further processing can proceed (Di Bono et al., 2012; Dormal, Seron, & Pesenti, 2006; Fabbri et al., 2012; Santiago, Román, Ouellet, Rodríguez, & Pérez-Azor, 2010; Vallesi et al., 2008 in Exp.5 of their study). Although magnitude comparison (e.g., "*which number/duration is smaller/shorter or larger/longer?*") is related to a size effect (e.g., Verguts & Van Opstal, 2005), in the temporal domain this effect has not been systematically found. On one hand, several papers have confirmed better performance (i.e., faster responses and higher accuracy) for short durations (milliseconds) or past words (temporal expressions) than long durations or future words (Fabbri et al., 2013a; Hartmann & Mast, 2012; Ishihara et al., 2008; Torralbo et al., 2006). On the other hand, Vallesi et al. (2008, 2011, 2014; see also Fabbri et al., 2013b for similar results in a temporal reproduction task) have reported faster responses for long than for short durations. Even if the authors explained this reversed size effect by the fact that all the participants were right-handed, in our opinion an additional explanation, related to the trial composition of the task, could explain these contradictory results. Vallesi et al. (2008, 2011, 2014) adopted a specific task in which participants estimated first the duration of a fixation cross (1 or 3 seconds of duration) and then waited for an arrow indicating the moment in which to give their response. Thus, it is possible that participants adopted a strategy to discriminate long durations, determining faster responses.

It is worth noting that SNARC- (Cappelletti, Freeman, & Cipolotti, 2007; Fabbri, 2011, 2013; Gevers, Lammertyn, Notebaert, Verguts, & Fias, 2006; Göbel, 2015; Hartmann, Gashaj, Stahnke, & Mast, 2014; Hartmann, Grabherr, & Mast, 2012; Ito & Hatta, 2004; Müller & Schwarz, 2007; Schwarz & Keus, 2004; Shaki & Fischer, 2012; Winter & Matlock, 2013) and STEARC-like (Bergen & Chan Lau, 2012; Fuhrman & Boroditsky, 2010; Hartmann, Martarelli, Mast, & Stocker, 2014; Leone, Salles, Pulver, Golombek, & Sigman, 2018; Ruiz Fernandéz, Lachmair, & Rahona, 2014; Stocker, Hartmann, Martarelli, & Mast, 2016; Woodin & Winter, 2018) effects have been found not only along horizontal, but also along vertical axes. The vertical SNARC and STEARC effects could be discussed according to grounded theory (Barsalou, 2008; Lakoff & Johnson, 1999), and especially to our conceptualization of quantities using the metaphor "*more is up*" (Lakoff, 1987). Vertical associations assume that quantities are represented through concrete sensorimotor experiences with the physical world. Based on common experience, it is reasonable to expect that magnitudes, such as numbers and time, are represented vertically from bottom to top space (Hartmann et al., 2012). Indeed, the word "*up*" is often associated with "*more*", and thus it is possible to find a preference for the vertical axis for quantities presented in real-life contexts (e.g., "*gas prices are rising*") as well as for linguistic expressions indicating the verticality of numbers and time (e.g., "*9 is a high number*" or "*Christmas is coming up*"; Lakoff & Johnson, 1980). According to this view, Fischer (2012) and Myachykov, Scheepers, Fischer and Kessler (2014) have discussed the vertical SNARC effect referring to the constraints of the physical world, a category to which the experience "more is up" belongs. In other words, it is possible to posit a bottom-to-top time representation because people often have experiences in daily life of "more time" along a vertical orientation, such as the growth process of a child to adulthood, or from a seedling to a plant, or buildings with several floors from the ground floor to the attic (Santiago, Román, & Ouellet, 2011), suggesting that "*a longer time corresponds with more time*" (e.g., a lighter feather takes more time to reach the ground). This assumption is not in conflict with the ATOM model, considering that neuroimaging studies have shown that the right posterior parietal cortex (PCC), 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 magnitudes (Bueti & Walsh, 2009; Cohen Kadosh, Cohen Kadosh, Schuhmann, Kaas, Goebel, Henik, et al., 2007; Cohen Kadosh et al., 2008; Walsh, 2013, 2015), suggesting that large numbers, for example, are perceived as longer in duration (Fabbri et al., 2012; Xuan et al., 2007).

However, the polarity correspondence account (Proctor & Cho, 2006) could predict an upward schema with short duration associated with the bottom and long duration associated with the top space. According to this account, when participants are required to classify temporal stimuli (i.e., short or long durations) by providing lateralized stimuli (down and up keys), both temporal and spatial features of response buttons are coded in bipolar dimensions, with long (future or later) durations and up-side responses being coded as positive polarities and short (past or earlier) durations and down-side responses being coded as negative polarities. In other words, long durations are coded with the + pole and short durations are coded with the – pole, as well as the up key being coded as the + pole and the down key being coded as the – pole. Consequently, corresponding polarities (i.e., short-down and long-up) induced a faster response selection, predicting a vertical spatial-temporal association. An alternative explanation is provided by the dual-route cognitive model, which seems to account for spatial-temporal associations, in line with what the dual-route model predicts for a SNARC effect (Gevers, Caessens, & Fias, 2005; Gevers et al., 2006). On one hand, the "conditional route" allows motor responses to be controlled in a very flexible way due to, for example, task instruction. On the other hand, the "unconditional route" conveys the automatic activation of pre-existing associations between stimuli and responses. The SNARC effect arises due to the automatic activation of the unconditional route in parallel with the conditional route. In congruent situations, both conditional and unconditional routes lead to the same stimulus-response association. In incongruent situations, the two routes activate different stimulus-response associations, given that the correct response is activated in the conditional route whereas the concurrent response is activated in the unconditional route. The influence of the unconditional route on motor response is stronger and the time necessary to activate the conditional route is longer, with a higher probability of triggering an incorrect response (Gevers et al., 2006). Given the analogy between the MNL and MTL (Bonato et al., 2012), it is conceivable that the dual-route model can predict the horizontal and vertical STEARC effect.

Irrespective of the account predicting a vertical spatial-temporal association, temporal concepts can be classified into three main categories: deictic time (D-time), sequence time (S-time), and duration (T-span). The first two definitions refer to past/future associations and those that take place earlier/later than an activity, implying an ordered sequence of events, while the T-span refers to quantifiable (short/long) durations (Núñez & Cooperrider, 2013). Indeed, the definition of time as duration could induce a more pronounced magnitude representation as seen in the temporal estimation task in which participants have to classify shorter (less than) or longer (more than) durations (in several time scales, milliseconds in Fabbri et al., 2012, 2013a,b or seconds in Vallesi et al., 2008, 2011, 2014) with reference to a fixed middle duration. However, to the best of our knowledge, no studies in the literature have tested the vertical representation of time as short/long durations, while the existence of a vertical representation of time as past/future or earlier/later has reported contradictory results. On one hand, a lack of convincing results has been observed. For example, Ishihara et al. (2008) asked participants to indicate whether the timing of a target stimulus (auditory click) was earlier or later than seven preceding stimuli, which were equally spaced (500ms interval). In the first experiment of their study, in which participants pressed two horizontally lateralized keys of an external response box, a preference was shown for right-sided responses when the target sound was presented later (after 215ms) than the expected interval time and a preference for left-sided responses when the target sound was presented earlier (before 215ms) than the expected timing. When, in their second experiment, the authors placed an external response box perpendicular to the midline of the participant's trunk in such a way that the response buttons were aligned vertically (i.e., the response keys were rotated by 90 degrees compared to the first experiment), the spatial-temporal association disappeared along the vertical dimension. This null effect has been found in other studies, using different temporal stimuli and response modality (Hartmann & Mast, 2012; Miles, Tan, Noble, Lumsden, & Macrae, 2011). For example, in their first experiment, Miles et al. (2011) asked English-speaking participants to categorize pictures of buildings/cities as being from the past or future using numerical keys of the standard keyboard such as 4 and 6 for the left-right and 2 and 8 for up-down responses. The results showed that participants were faster at categorizing past and future when using the horizontal response keys but not when using the vertical ones (see also the study by Hartmann and Mast, 2012, in which participants categorized past, such as World War II, and future, such as holidays on Mars, and also verbal stimuli during forward/backward or upward/downward motion). Finally, Woodin and Winter (2018) found that the words past and future, as well as the words earliest, earlier, later, and latest, were placed in a horizontal dimension when participants were free to place stimuli wherever they wished in the space (while words such as most, more, less, or least, representing quantity, showed a vertical bottom-to-top representation). On the other hand, Ruiz Fernandéz et al. (2014) found faster responses to a square positioned in the upper space when a future-related word was paired with the target stimulus whereas faster responses were found for a square positioned in the lower space when it was paired with a past-related word. At the same time, Hartmann et al. (2014) found past-left/down and future-right/up associations when participants were required to mentally displace themselves in time to their personal past or future. When participants were requested to process different temporal relations in language (before, after, or same-time), Stocker et al. (2016) also showed more upward saccades when processing "after" than "before" sentences, suggesting an upward direction of the mental time line (Lakoff & Johnson, 1980). Finally, Leone et al. (2018) showed that time events were chronologically ordered rightward and upwards, especially when participants mapped “zones of time”, such as the past, present, and future. Moreover, some of the studies reporting a vertical space-time association have shown an opposite direction, contrary to the expected bottom-to-top orientation in which magnitude is associated with “higher up” (Bergen & Chan Lau, 2011; Miles et al., 2011; Yang & Sun, 2016), especially for Mandarin speakers due to the vertical reading/writing experience. In Western culture, by contrast, the dominant reading direction is from left to right and thus neutral with respect to the vertical dimension (Casasanto & Bottini, 2014b; Hartmann & Mast, 2012; Ishihara et al., 2008; Miles et al., 2011). However, even in Western culture, most reading and writing habits in children and adults involve more than one line of text, and thus it is possible to advance the idea that reading and writing systems have a secondary direction, that is line-by-line, from the top to the bottom of a page. This secondary reading direction, for instance, most likely influences the spatial-numerical association, as found by Göbel (2015), who reported that the majority of English participants count vertical arrays from top to bottom. Thus, it remains to understand whether temporal concepts (e.g., past/future or earlier/later as used by Casasanto & Bottini, 2014b; Hartmann & Mast, 2012) are represented along a vertical line (and in which direction) and whether temporal durations (Fabbri et al., 2013a,b; Vallesi et al., 2008, 2011, 2014) are associated with the vertical space, given that no studies address this possibility.

In our opinion, some methodological aspects should be taken into account when addressing the vertical spatial-temporal association. It may be that the use of auditory stimuli (e.g., Ishihara et al., 2008) and/or the presentation of central stimuli (Hartmann & Mast, 2012; Miles et al., 2011) did not capture the salience of vertical perception. The vertical dimension, for instance, could be strengthened using visual stimuli on the vertical axis, thus increasing a peripheral congruency effect (see Shaki & Fischer, 2018 for this assumption with numbers). Indeed, it has been observed that responses to temporal durations (expressed in milliseconds, as in the present research) were influenced by task-irrelevant visuospatial cues, with leftward cues determining faster responses to short duration and rightward cues determining faster responses to long durations (Di Bono et al., 2012; Vicario, Pecoraro, Turriziani, Koch, Caltagirone, & Oliveri, 2008). Furthermore, temporally characterized words presented in the right space were associated with the future whereas those presented in the left space were associated with the past (Fuhrman & Boroditsky, 2010; Ouellet et al., 2010a; Santiago et al., 2007; Torralbo et al., 2006; Weger & Pratt, 2008). Altogether these studies seem to suggest that space-time interactions arise when a temporal task is characterized by a spatial aspect, independently of its association with lateralized response keys or with spatial lateralization of the target (see Keus & Schwarz, 2005 for numerical domain). The importance of considering the stimulus position has been repeatedly demonstrated, as shown, for example, by the Simon effect (Simon, 1990) found in both the horizontal and vertical arrays (e.g., Ansorge & Wühr, 2004; Gevers et al., 2005; Vallesi, Mapelli, Schiff, Amodio, & Umiltà, 2005).

From a methodological point of view, it is important to clarify the term “vertical” (Hartmann et al., 2014; Winter et al., 2015a). In fact, all studies investigating space-magnitude interaction vertically can be subdivided in two ways: the term “vertical” can be interpreted in a two-dimensional (2-D) context where the vertical axis refers to the axis perpendicular to the horizontal axis (e.g., when reading a page; response pad or keyboard positioned on a horizontal plane), and in a 3-D context in which the vertical axis is perpendicular to the horizontal plane (e.g., when the keyboard is positioned vertically). In the numerical domain, a vertical SNARC effect has been found both when the vertical dimension has been adopted (Fabbri, 2011, 2013; Gevers et al., 2006; Göbel, 2015; Ito & Hatta, 2004; Müller & Schwarz, 2007; Shaki & Fischer, 2012), generally using the numeric keypad with the “2” key as the lower key and the “8” key as the higher key, and when a literal meaning of vertical space has been applied (Hartmann et al., 2012, 2014; Schwarz & Keus, 2004), while in the time domain spatial-temporal associations along the vertical axis have been found using a 2-D meaning of vertical space only (Bergen & Chan Lau, 2012; Miles et al., 2011 Tversky et al., 1991; Yang & Sun, 2016), but not with a literal meaning of verticality (Ishihara et al., 2008). Although Winter et al. (2015a; see also Göbel, 2015; Hartmann et al., 2014) stated that the use of the “2” and “8” numerical keys resembles more a radial (or near-far responses) than a vertical dimension, it has been confirmed that “down” (2) or “up” (8) response keys on the keyboard could be equivalent to the vertical dimension of the response buttons (Ito & Hatta, 2004; Rusconi, Kwan, Giordano, Umiltà, & Butterworth, 2006; Vu, Proctor, & Pick, 2000). In addition, when someone writes or reads a piece of paper positioned flat on a table, the head changes its orientation to look at the paper and thus the spatial positions are defined more as up (top of the piece of paper) and down (the bottom part of the paper) than far and near space (i.e., radial/sagittal space). Finally, the “2” and “8” keys on the numerical keypad could indicate low and high space considering that these keys generally depict arrows pointing downward and upward respectively, a specific spatial indicator that is used to move a cursor along a vertical screen.

Another methodological issue involves the possible confounding effect between the spatial location of response keys and the hand used to respond. In the numerical domain. Ito and Hatta (2004) performed two experiments with the participant’s left hand assigned to the bottom key and the right hand assigned to the top key, as well as with an opposite assignment of response hand. They obtained similar results between experiments suggesting that number magnitude was associated with the vertical position of responses but not with the response hands (see also Shaki & Fischer, 2012). 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. When the vertical space-time interaction was studied, these methodological issues were not controlled for, given that in Ishihara et al.'s study (2008) all participants pressed the bottom key with their left hand and the top key with their right hand, whereas in Miles et al.'s study (2011) both keys were pressed with the right index finger.

The present study aimed to clarify which kind of space-time association can be obtained in the vertical dimension using a time estimation task of millisecond intervals. We adopted the same experimental procedure used by Fabbri and colleagues (Fabbri et al., 2013a, b), presenting reference stimuli (fixed duration, 400 ms) and target stimuli (varying duration, 200-600 ms) on the screen. Contrary to previous studies, we decided to test a possible vertical congruency between visually presented stimuli and spatial position of response keys. Thus, in Experiment 1, the target stimulus appeared at the top, middle or bottom of the screen, whereas in Experiment 2, the same spatial modification was carried out for the reference stimulus. According to the metaphor "more is up," we expected to find faster and more accurate responses when participants judged short durations using the bottom key and longer durations using the top key, suggesting a vertical time-space association (Hartmann et al., 2014; Leone et al., 2018; Ruiz Fernandéz et al., 2014; Stocker et al., 2016). However, a possible downward direction (i.e., associations between short durations and the top key as well as between long durations and the bottom key) could be expected according to the experience of reading/writing. In fact, the habit of reading and writing (i.e., reading/writing direction account) from the top of the page towards the bottom of the space could be a concrete sensorimotor experience with a real context (Bergen & Chan Lau, 2012; Casasanto & Bottini, 2014b; Chen, 2007; Miles et al., 2011; Yang & Sun, 2016). For example, reading an article on a computer screen can mean starting from the top of the screen and progressively moving downwards. In many Italian online newspapers, many articles report the estimated reading time and longer reading times may correspond to moving further down the screen. Thus, the decision to spend time reading one article instead of another could be based on "*how many scroll downs are required*" or "*how many eye movements towards the bottom space are needed*". Thus, the sensorimotor (the eyes move downward and/or the hand that, through the cursor, moves the vertical bar of the screen downwards) experience of reading and writing could overlap with the Western cultural dominant reading direction from the top to the bottom of the page. Finally, any null effects would confirm that the evidence for a vertical time representation is contradictory, with some studies failing to find an association (Hartmann & Mast, 2012; Ishihara et al., 2008; Miles et al., 2011; Woodin & Winter, 2018), others finding an upward association (Hartmann et al., 2014; Leone et al., 2018; Ruiz Fernandéz et al., 2014; Stocker et al., 2016), and some even finding a downward association (Bergen & Chan Lau, 2011; Casasanto & Bottini, 2014b Yang & Sun, 2016), thus cancelling each other out. In order to control for any confounding effects related to hand-based frame of reference, in both experiments, we subdivided participants into two groups based on hand assignment to top or bottom response keys. Moreover, in both experiments the instructions emphasized the vertical position of response keys with no emphasis on the hand used to respond. These methodological procedures allowed us to verify whether time was represented in terms of extracorporeal space or whether time was related to the specific spatial representation of hands. We also expected to find both distance and size effects in our experiments, considering that participants were requested to perform a (direct and explicit) temporal estimation task (i.e., a magnitude comparison), in line with the literature (Bruzzi et al., 2017; Chang & Cho, 2015; Cohen Kadosh et al., 2008; Cohen Kadosh & Henik, 2006; Dalmasio & Vicario, 2019; Di Bono et al., 2012; Dormal et al., 2006; Fabbri et al., 2012, 2013a; Fias et al., 2003; Fulbright et al., 2003; Fumarola et al., 2014; Gevers et al., 2003, 2004; Hartmann & Mast, 2012; Ishihara et al., 2008; Moyer & Landauer, 1967; Pinel et al., 2004; Rusconi et al., 2006; Santiago et al., 2010; Sellaro et al., 2015 Torralbo et al., 2006; Verguts & Van Opstal, 2005). Both effects would add further evidence of the MTL: temporal durations are placed in a "specific position" along the line, facilitating (or reducing) the temporal comparison between reference duration and shorter/longer target durations. Although contradictory results were found for the size effect, we expected this effect to be present, due to the fact that we adopted (and displaced vertically) the same temporal estimation task (and experimental procedure) provided by Fabbri et al. (2013a), who found a size effect with two horizontal response keys.

2. EXPERIMENT 1

We asked participants to perform a temporal estimation task in which visual stimuli were presented on the screen at millisecond intervals. A reference stimulus (a yellow rectangle) was always presented at the centre of the screen for 400 ms, whereas the target stimulus (a light blue rectangle) lasted for a shorter or longer time than the reference stimulus and appeared in one of three spatial positions: at the bottom, centre, or top of the screen. The task required participants to judge whether the target stimulus lasted for a shorter or longer time than the reference stimulus. This task was carried out twice, with two vertical response buttons, determining a congruency between the spatial position of the target on the screen, the temporal duration of target, and the spatial position of the response keys (Santiago et al., 2007).

2.1 Methods

2.1.1 Participants

In the reviewed literature, regarding vertical spatial-temporal associations, we calculated the mean number of participants enrolled in the studies. In general, a mean of 31.61 participants was considered (Ishihara et al., 2008: 30 participants in their second experiment; Miles et al., 2011: 44 participants in the first experiment and 32 individuals in the second one; Hartmann & Mast, 2012 tested 32 participants in each experimental study; Casasanto & Bottini, 2014b: 18, 20 and 22 for every created condition; Bergen & Chan Lau, 2012: 10 English, 33 Chinese and 38 Taiwanese participants; Yang & Sun, 2016: 60 for the study 1 and 40 for the study 2). Thus, we recruited a group of 32 Italian students (18 females, 14 males; mean age= 28.75 years; SD= 5.28 years) who volunteered to participate in the experiment. Even if our sample size was similar to that reported in previous studies, we also decided to report the observed statistical power (1-β, reported in the tables of Supplementary Materials).

The participants filled in the Edinburgh Handedness Inventory (EHI; Oldfield, 1971). Based on the EHI scores, 30 were right-handed (M = +63.67; SD= 41.40) and 2 were left-handed (M = -43.16; SD= 23.82). Data from 6 participants (3 females and 1 male of Group A as well as 1 male and 1 female of Group B; see Procedure section below) were not included because their accuracy performance was on average equal to 56.83% (SD = 11.57%), which was significantly lower than the included participants whose performance was on average equal to 87.85% (SD = 4.97%), with $t(30) = -10.46$, $p < .0001$, *Cohen's d* = 3.48. All results presented are based on the remaining 26 participants (14 females, 12 males; mean age= 26.29 years; SD= 5.26 years; 24 right-handed and two left-handed). All participants had normal or corrected-to-normal vision and they provided written informed consent. Participants were not informed as to the purpose of the study. The study was conducted following university ethical guidelines and it was approved by the Ethical Committee of University of Bologna.

2.1.2 Apparatus and Materials

All stimuli were presented on the dark background of a COMPAQ V570 computer screen (1024 x 768 pixels). All participants sat facing the computer screen at a viewing distance of 60 cm.

The stimuli consisted of two rectangles in a temporal estimation task. The reference stimulus was a yellow rectangle (192 pixels in length × 128 pixels in height; 6.77 x 4.51 cm) and the target stimulus was an equally sized light blue rectangle. The reference–target pairs were displayed in three spatial combinations: (1) centre-bottom (C-B), (2) centre-centre (C-C), or (3) centre-top (C-T). The x- and y-coordinates for the bottom, centre, and top positions were, respectively, (a) 480 × 268 pixels (16.93 x 9.45 cm), (b) 480 × 536 pixels (16.93 x 18.91 cm), and (c) 480 × 804 pixels (16.93 x 28.36 cm). The coordinates indicate the centres of the rectangles.

2.1.3 Procedure and Task

All participants were individually tested in a quiet room. Stimulus presentation and data collection were controlled using E-Prime 2.0 (Schneider, Eschman, & Zuccolotto, 2002). The participants were required to judge whether the duration of a target stimulus (light blue rectangle) appearing on the screen was shorter or longer than that of a reference stimulus (yellow rectangle). The duration of the reference cue was fixed across trials (400 ms). The duration of the target could range from 200 to 600 ms in increments of 100 ms (except 400 ms). The durations of 200 and 300 ms were considered short durations, whereas the durations of 500 and 600 ms were considered long durations. The response keys were the “2” (or down) and “8” (or up) keys of the numerical keypad on a standard keyboard and these keys were covered by two green discs in order to avoid any spatial (i.e., the depicted upward and downward arrows) influence. The upper and lower response keys were centrally aligned with respect to the body midline. Participants were randomly split into two groups and, for each group, the task was performed twice, using two different blocks, in which the instruction–key assignments were counterbalanced. In one block, group A had to press the “2” key with their left hand to indicate that the duration of the light blue rectangle was shorter than the duration of the yellow rectangle and the “8” key” with their right hand to indicate that the duration of the target was longer than that of the reference stimulus. In the other block, the allocation of the two response keys to short or long durations was switched but the assignment of the hands to the response keys was constant within participants throughout the experiment. The same procedure was adopted for group B with the exception that the left hand was assigned to the up key and the right hand to the down key. For both groups, the instruction strongly emphasized the spatial position of the response buttons only, with no emphasis on the hand used to respond. Each trial started with a white cross (+) sign in Courier New 120-point type that appeared at the centre of the screen as a fixation point for 400 ms. After the fixation point, a black screen appeared for 1000 ms. Following that, a yellow rectangle (the reference stimulus) appeared centrally on the screen against a black background. The reference cue lasted 400 ms in all trials. Then, a black screen appeared as an interstimulus interval (ISI). In order to avoid any response strategy, this black screen lasted for a randomly selected interval value between 700 and 800 ms. After this ISI, a light blue rectangle (the target stimulus) appeared on a black background in the bottom, centre, or top position. The participants were instructed to refrain from making a judgment until after the presentation of the target stimulus, when a white question mark ("?") in Courier New 120-point type appeared at the centre of the screen on a black background. It was presented with a "beep" sound (lasting for 1 second with 11.025 Hz) in order to prompt participants to make a judgment by pressing one of the corresponding keys. The question mark remained on the screen for 1500 ms or until the participant's response was given. Finally, the new fixation point appeared after a black screen of 400 ms (Figure 1a). In each block, 120 trials were presented in a pseudorandom order for a total of 240 trials. Before the test, a training session was run, with 12 trials presenting all three spatial positions of the target stimuli that lasted from 200 to 600 ms. The training phase could be performed for a second time if requested by the participants. After each block, individuals had the opportunity to take a 1-min break. The experiment lasted approximately 30 min.

Please insert Figure 1 about here

2.1.4 Data analysis

The mean reaction time of correct responses was calculated. RTs more than 3 SDs above or below the mean were discarded as outliers (about 3,18%). The data in the study were evaluated using IBM SPSS Statistics for Windows, version 20.0. A four-way mixed analysis of variance (ANOVA) was carried out on correct RTs, with Group (A vs. B) as the between-subject factors and Response Position (down key vs. up key), Duration (200, 300, 500, and 600 ms), and Stimulus Location (bottom, centre or top) as within-subject factors. The same ANOVA was carried out on numbers of errors (NEs). When a significant interaction was found, a post-hoc test with Bonferroni's correction was run. The criterion set for statistical significance was $p < .05$.

2.2 Results

All descriptive data (means and relative standard deviations) for RTs (in ms) and accuracy (as NEs) are displayed in Table S1 (see Supplementary Materials). Table S2 (see Supplementary

Materials) reports the statistical (*F*, *p*, η^2_p, and *1-β*) results of the ANOVA on both dependent variables.

Regarding RTs, we found a significant Duration effect and Response Position x Duration interaction (Figure 2a). The former result demonstrated that the short 300 ms target duration (M=579 ms; SD=147 ms) determined slower RTs than those reported when the short 200 ms target duration (M=511 ms; SD=139 ms) and long 600 ms target duration (M=495 ms; SD=130 ms) were distinguished, with $p < .0001$ for both comparisons. In addition, estimation of the long 500 ms target duration (M=551 ms; SD =142 ms) showed higher RTs than those found for the short 200 ms and long 600 ms target durations ($p < .005$). The post-hoc test for interaction did not reveal any significant comparisons between the down key and the up key for short and long target durations.

To investigate the STEARC effect found, we ran the regression analysis in an analogous manner to previous methods used to assess the SNARC effect (Dehaene et al., 1993). As far as the STEARC effect was concerned, first we calculated the RT differences (or dRT in ms) between the down key and up key responses for short and long target durations. Then we calculated the linear regression coefficient predicting these values [x: target durations; y: dRT] (Figure 3a). Negative slopes of the regression line indicated participants who showed the STEARC effect with "Down-Short" and "Up-Long" associations (i.e., bottom-to-top mapping), whereas positive slopes of the regression line indicated participants who showed the reversed STEARC effect with "Down-Long" and "Up-Short" associations. Only 6 out of 26 (including five right-handed and one left-handed) participants showed a reversed STEARC effect. Finally, we calculated the unstandardized regression coefficient (b) for each individual, which indicated the slope of the line. The main coefficient was regarded as the overall effect of the variable and a one sample t-test was used to test whether this mean effect differed significantly from zero (Van den Noortgate & Onghena, 2006). In our study, the average regression coefficient (b = -0.26 ms; SD=0.45 ms) differed significantly from zero, ($t\,(25) = -2.97$, $p = .006$, *Cohen's d* = 0.58) and the best-fitting regression line was described by the equation dRT = 97.31 – 0.26 * (duration).

For NEs, the ANOVA (Table S2) showed a significant effect of Duration only, reflecting a Distance effect. The post-hoc test mirrored the RT results, with higher NEs for the 300 ms target duration (M=1.30; SD=0.58) than for all other target durations ($p < .001$ for all comparisons). In addition, the 500 ms target duration (M=0.62; SD=0.47) determined higher NEs than those obtained for both 200 ms (M=0.23; SD=0.27) and 600 ms (M=0.27; SD=0.28) target durations ($p < .001$ for both comparisons).

Finally, in a debriefing session, we asked participants to report whether they perceived the response keys to be more vertically or radially (near-far) oriented ("*How did you really perceive the response keys used in the experiment? Are they more vertically oriented or are they more radially oriented?*"). All participants reported that the "8" key was perceived as the upper button whereas the "2" key was perceived as the lower button. None of the participants reported a radial orientation of the response buttons.

Please insert Figure 2 about here

Please insert Figure 3 about here

2.3 Discussion

In a temporal judgment task using millisecond durations, we studied a space-time interaction by vertically presenting a target stimulus to be judged as shorter or longer than a reference stimulus (always presented centrally) along the vertical dimension, measured using two vertical response keys. By means of modifying several methodological aspects of previous studies (Casasanto & Bottini, 2014b; Hartmann & Mast, 2012; Ishihara et al., 2008; Miles et al., 2011), the purpose of the present study was to assess whether a space-time interaction could arise along the vertical axis.

Our results clearly showed a STEARC effect on the vertical axis in a similar way to the SNARC effect reported vertically (Fabbri, 2011, 2013; Cappelletti et al., 2007; Gevers et al., 2006; Hartmann et al., 2014; Ito & Hatta, 2004; Müller & Schwarz, 2007; Schwarz & Keus, 2004; Shaki & Fischer, 2012). According to the metaphor "more is up", participants responded faster to short durations when pressing the down key compared to the up key, and vice versa for long durations (Figures 2a and 3a). This result pattern is in line with a vertical representation of numbers, with large numbers associated with the top space and small numbers associated with the bottom space (Fischer, 2012; Gevers et al., 2006; Winter & Matlock, 2013). This could be explained by an analogy: we have all experienced a seed that over time grows to become a plant, or more generally, know that gravity may determine the ground as a zero point and is used as reference for general magnitude associations.

Furthermore, we did not find any group differences, suggesting that time was represented in extracorporeal space (Vallesi et al., 2008), on which the spatial position of keys, and not the bodily effector (hand used to respond), played the crucial role, in a similar way to number representation. Moreover, during the debriefing all participants reported that the up key was perceived as upper space, whereas the down key was perceived as lower space, even if we used a metaphorical meaning of the term "vertical" in a two-dimensional context (Vu et al., 2000). In addition, we found a distance effect for temporal duration vertically, in a similar way to the "classical" distance effect in the temporal domain (Di Bono et al., 2012; Dormal et al., 2006; Fabbri et al., 2012; Santiago et al., 2010; Vallesi et al., 2008). This finding may add support to the bottom-to-top time representation with each duration placed on a vertical analogical timeline. Moreover, it is possible that the distance effect confirms the hypothesis that the temporal stimuli (T-span) used in the present study were considered as another type of magnitude, thus adding evidence to the existence of shared magnitude representation (Cohen Kadosh et al., 2008; Lourenco & Longo, 2010; Walsh, 2003). However, we did not find any size effect. As found in the numerical domain (Verguts & Van Opstal, 2005), this type of dissociation between distance and size effects might indicate that the size effect did not originate from the MTL but from other mechanisms. At the same time, this finding may indicate that a discrete semantic system (DSS), instead of the analogue time system (ATS in line with the analogue number system or ANS) is involved in temporal processing, as has been proposed for numbers (Krajcsi, 2017). Nevertheless, it cannot be excluded that the creation of two groups according to the assignment between hand and key to be pressed masked any size effect.

However, our results could be explained by the polarity account (Proctor & Cho, 2006). For a variety of binary classification tasks, people code the stimulus alternatives and the response alternatives as (+) polarity and (-) polarity, and response selection is faster when the polarities correspond than when they do not. The temporal (short and long) and the spatial features of response buttons (down and up, in our study) are coded in a bipolar dimension and corresponding polarities induce faster response selection. In other words, the STEARC effect found here could be due to the corresponding polarities between up and long (both +) and down and short (both -). Alternatively, the dual-route cognitive model could account (Gevers et al., 2006; Keus & Schwarz, 2005) for the bottom-to-top representation of temporal durations. As regards numerical processing, the model describes how magnitude may gain control over motor responses through different routes of information processing. Indeed, the space-time association may be related more to motor than perceptual components in the vertical dimension, as evidenced by a study in which the use of horizontal response keys to assess a spatial representation of time produced a response code that pre-activated the corresponding motor cortex and determined faster responses in left-short and right-long mapping (Vallesi et al., 2011). Specifically, Vallesi et al. (2011) required participants to discriminate between short and long durations with horizontal bimanual responses when electrophysiological data were recorded. When analyzing the electrical activity from the hand-motor cortices of both hemispheres, the authors found that the spatial representation of time produced a response code that pre-activates the corresponding motor cortex and sped up responses when there was compatible mapping between short/left and long/right (but not when there was incompatible mapping). Thus, the upward flow of time probably extends to the response preparation stage, affecting motor performance in a similar way to that found in the horizontal STEARC effect (Bonato et al., 2012; Fabbri et al., 2013a,b; Ouellet et al., 2010a,b; Santiago et al., 2007; Torralbo et al., 2006). The relevance of motor versus perceptual components in the spatial-temporal association could be explained by the fact that external physical space codes were linked to the spatial position of the target which had to be judged as shorter or longer than that provided by the reference stimulus. Taking into account that the duration of the reference stimulus (yellow rectangle) had to be estimated by participants in order to perform the task, in Experiment 2 we decided to spatially vary the reference stimulus while the target stimuli remained fixed in the central position. In this way, the spatial information was conveyed by the reference stimulus, whereas the temporal information was mainly conveyed by the target. In addition, it was hypothesized that while participants were estimating the duration of the reference stimulus, they were also processing its spatial position. This spatial processing may have "primed" the subsequent temporal processing when there was compatibility between space and time (Di Bono et al., 2012; Vicario et al., 2008). According to the results of Experiment 1, we defined "compatibility" as the correspondence between short duration and bottom space and between long duration and top space.

3. EXPERIMENT 2

In this study, the experimental methods and procedures were the same as those used in Experiment 1, with the following exception: the reference stimulus (a yellow rectangle) position could appear in one of three spatial positions (at the bottom, centre, or top locations) on the screen, whereas the target stimulus (a light blue rectangle) was always presented at the centre of the screen. With this manipulation, we hypothesized that the spatial processing of the reference stimulus could facilitate (or inhibit) the subsequent short/long judgment, according to the vertical STEARC effect found in the previous experiment (and in line with the metaphor "more is up"). As for the previous experiment, we also expected to see a distance effect, while no size effect was predicted.

3.1 Methods

3.1.1 Participants

A group of 32 new students (23 females, 9 males; mean age= 21.94 years; SD= 2.86 years) volunteered to participate in the experiment. The participants filled in the EHI (Oldfield, 1971), and in the sample, there were 29 right-handed (M = 82.55; SD = 16.99) and 3 left-handed participants (M = -60.93; SD = 11.77). Data from 4 participants (1 female of Group A and 3 females of Group B) were not included because their overall accuracy was equal to 61.25% (SD = 10.12%) compared to the remaining participants who scored an accuracy level of 87.48% (SD = 5.89%), with $t(30) = -7.62$, $p < .00001$, *Cohen's d* = 3.17. All results were based on the remaining 28 participants (19 females, 9 males; mean age= 21.86 years; SD= 2.95 years; 26 were right-handed and two were left-handed). All participants had normal or corrected-to-normal vision and they provided written informed consent. Participants were not informed as to the purpose of the study. The study was conducted following university ethical guidelines and it was approved by the Ethical Committee of University of Caserta.

3.1.2 Apparatus, Materials, Procedure and Task

Apparatus, materials, procedure and task were the same as those used in Experiment 1 with the only difference being that the reference stimulus could appear in different positions of the screen (Figure 1b), while the target stimulus was always presented in the centre. The reference-target pairs were displayed in three spatial combinations: (1) bottom-centre (B-C; 268 × 480 pixels or 9.45 x 16.93 cm), (2) centre-centre (C-C; 536 × 480 pixels or18.91 x 16.93 cm), or (3) top-centre (T-C; 804 × 480 pixels or 28.36 x 16.93 cm).

3.1.3 Data analysis

RTs more than 3 SDs above or below the mean were discarded as outliers (about 3.11%). A four-way mixed ANOVA with Group (A vs. B), as the between-subjects factor, and with Response Position (down key vs. up key), Duration (200, 300, 500, and 600 ms), and Stimulus Location (bottom, centre or top), as within-subjects factors, was carried out on correct RTs and NEs. When a significant interaction was found, a post-hoc test with Bonferroni's correction was run. The criterion for statistical significance was set at $p < .05$.

3.2 Results

All descriptive data (means and relative standard deviations) for RTs (in ms) and accuracy (as NEs) are displayed in Table S3 (see Supplementary Materials). Statistical values (*F*, *p*, η^2_p, and *1-β*) of the ANOVA for both dependent variables are reported in Table S4 (see Supplementary Materials).

As far as RTs were concerned, the ANOVA revealed a significant main Duration effect, reflecting longer responses for the 300 ms target duration (M=472 ms; SD=99 ms) than for all other target durations ($p < .0001$ for all comparisons). Furthermore, a significant interaction between Response Position and Stimulus Location was found. The post-hoc test indicated that the down key determined faster responses than the up key for the top space (M=409 ms and SD=86 ms vs. M=438 ms and SD=109 ms, respectively), with $p < .05$. No other comparisons were found. More importantly, there was a significant interaction between Response Position and Duration, suggesting a STEARC effect. The post-hoc test did not reveal any significant comparisons, even if Figure 2b displayed faster responses for short durations when the down key was pressed and for long durations when the up key was pressed than for the opposite scenario. As in Experiment 1, we ran a regression analysis for the repeated measures design (Van den Noortgate & Onghena, 2006). RT differences between down key responses and up key responses for short and long target durations were calculated at the individual level and a linear regression was then applied [x: target durations; y: RT differences or dRT (ms)] (Figure 3b). Nine out of the 28 participants (including all right-handed participants) showed a reversed STEARC effect. As in Experiment 1, the average non-standardized regression coefficient (b = -0.17 ms; SD=0.44 ms) did not differ significantly from zero ($t(27) = -2.03$, $p = .052$, *Cohen's d* = 0.39), even though the majority of participants showed the STEARC effect for bottom-up mapping, quantified by the general equation dRT = 72.02 – 0.17* (duration).

The same ANOVA on NEs (Table S4) showed Duration and Stimulus Location effects. For the former effect, the 300 ms target duration (M=0.95; SD=0.46) determined higher NEs than those found for the 200 ms target duration (M=0.36; SD=0.37); the 500 ms target duration (M=0.61; SD=0.48) also determined higher NEs than those found for the 200 ms target duration ($p < .05$ for both comparisons). For the latter effect, when the reference stimulus appeared at the bottom of the screen (M=0.51; SD=0.33) NEs emerged as lowercompared to when the reference stimulus was placed at the top of the screen (M=0.72; SD=0.37), with $p < .05$. Finally, a Group x Duration interaction was found. When the 500 ms target duration was analyzed, the post-hoc test revealed higher NEs for Group A (M=0.78; SD=0.52) than those for Group B (M=0.42; SD=0.35), with $p < .05$. No other comparisons were statistically significant.

Finally, in a debriefing session, we asked participants to report whether they perceived the response keys as being more vertically or radially (near-far) oriented ("*How did you really perceive the response keys used in the experiment? Are they more vertically oriented or are they more radially oriented?*"). All participants reported that the "8" key was perceived as the upper button whereas the "2" key was perceived as the lower button. None of the participants reported a radial orientation of the response buttons.

3.3 Comparisons between Experiments

To compare both experiments, we performed a mixed ANOVA with Experiment (1 vs. 2) and Group (A vs. B) as between-subjects factors and with Response Position (down key vs. up key), Duration (200, 300, 500, and 600), and Stimulus Location (bottom, centre, or top) as within-subjects factors on RTs, given that we observed the spatial-temporal association for RTs only (Table S5; see Supplementary Materials).

The ANOVA on RTs revealed a significant main Experiment effect. In Experiment 2 (M=424 ms; SD=83 ms) participants were faster at temporal judging than those in Experiment 1 (M=534 ms; SD=131 ms). In addition, the ANOVA showed a Duration effect, suggesting higher RTs for the 300 ms target duration (M=524 ms; SD=134 ms) than all other durations ($p < .0001$ for all comparisons). In addition, higher RTs were determined for the 500 target duration (M=477 ms; SD=134 ms) than those for the 600 target duration (M=448 ms; SD=116 ms), with $p < .005$. The Experiment factor interacted with Duration significantly, mirroring the general Experiment effect. Indeed, for all durations, participants in Experiment 2 produced faster responses than participants in Experiment 1 ($p < .005$ for all comparisons). More importantly, a significant interaction between Response Position and Duration was found, reflecting a STEARC effect. Indeed, the down key (200 ms: M=444 ms and SD=126 ms; 300 ms: M=503 ms and SD=147 ms) determined faster responses than the up key (200 ms: M=475 ms and SD=144 ms; 300 ms: M=544 ms and SD=150 ms) for shorter durations (Figure 2), with $p < .05$. By way of contrast, the up key (500 ms: M=454 ms and SD=139 ms; 600 ms: M=432 ms and SD=116 ms) determined faster responses than the down key (500 ms: M=500 ms and SD=153 ms; 600 ms: M=464 ms and SD=133 ms) for longer durations, with $p < .05$. To further test this general vertical STEARC effect, we compared the b values of regression analyses reported for both experiments. We did not find significant differences between experiments for the mean b value ($t(52) = -0.79$, $p = .43$, *Cohen's d* = 0.20). Finally, we found a significant triple Group x Duration x Stimulus Location interaction. This interaction indicated that in at the bottom of the space Group A reported faster responses than Group B for all durations, with the exception of the 300 ms target duration. No other main effect or interaction reached statistical significance, as shown in Table S5.

To further explore this space-time interaction, we collapsed the data from both experiments and divided the RTs into quintile-bins for each participant, response side, and durations (short = 200 and 300 ms; long = 500 and 600 ms), in line with the method used for the SNARC effect (Hartmann et al., 2014; Wood et al., 2008). Figure 4 shows that a vertical STEARC effect emerged as a robust pattern across all levels of RT bins, with the exception of faster responses (bins 1 and 2) for the down key (Figure 4a), whereas for the up key (Figure 4b) the STEARC effect was more constant across all RT bins, in a similar way to the classical SNARC effect (Wood et al., 2008), with a larger STEARC effect for longer RTs.

Please insert Figure 4 about here

3.4 Discussion

The aim of this second experiment was to replicate the findings of Experiment 1, while presenting a reference stimulus that varied vertically and a central target stimulus whose location was held constant. Specifically, with this procedure, we expected the presentation of the reference stimulus (i.e., yellow rectangle) to somehow “prime” part of the temporal line and simplify the choice of “up” or “down” key in response to the short/long stimulus durations.

The results confirmed a set of findings found in Experiment 1. First of all, we found a STEARC effect along the vertical axis, with faster RTs noted when indicating short durations with the down key and faster RTs noted when judging long durations with the up key, as predicted by the metaphor “more is up” (Fischer, 2012; Gevers et al., 2006; Hartmann et al., 2012, 2014; Lakoff & Johnson, 1980; Shaki & Fischer, 2012; Winter & Matlock, 2013). Again, the experimental methods used here could account for the different results obtained by previous studies. This vertical spatial-temporal association was also confirmed not only by the omnibus ANOVA performed for experiment comparisons, but also by the data shown in Figure 4 demonstrating that this STEARC effect tended to be stronger for slower responses, especially when participants used the up key response button, similar to (horizontal and vertical) SNARC effect (Wood et al., 2008). Secondly, the space-time interaction seemed to depend more on extracorporal space defined by the spatial position of response keys than the spatial position of the hands (Müller & Schwarz, 2007; Vallesi et al., 2008). Just as in Experiment 1, the use of the “2” and “8” numeric keys of the keypad resembled and were perceived as down and up keys, respectively, by participants, in debriefing. However, we found an interaction between Group and Duration when NEs were analyzed. Specifically, we found that Group B (i.e., left hand assigned to the up key and right hand assigned to the down key) reported fewer NEs for long durations (especially for the 500 target duration) compared to Group A (with the opposite assignment of hands to the response keys). Thus, this hand position could influence the processing of time. Nevertheless, the significant Experiment effect as well as its interaction with Duration in the omnibus ANOVA for experimental comparison could exclude any role of hand position effect on time estimation. In other words, it would be more convincing to attribute this interaction to the impact of different experimental settings that influenced the time estimation of short/long stimuli, more than to the hand-key assignment. Thirdly, we confirmed that the STEARC effect is related more to motor than perceptual components in the vertical dimension (Vallesi et al., 2008, 2011), even when the spatial information was conveyed by the reference stimulus while the temporal information was conveyed by the target. Fourth, the distance effect was found, suggesting a lower level of performance for target durations that were close to that of the reference stimulus (especially for the 300 ms target duration). This finding suggests that temporal durations may have been placed on a (vertical) timeline and that this representation was activated to perform the task. Statistically, no size effect was found, indicating a dissociation between distance and size effects. However, a thorough inspection of Figure 2b could reveal a reversed size effect, with faster responses to long durations. Although a possible interpretation could be related to the number of right-handed subjects in the sample, we could speculate that the trial composition of the task is an alternative interpretation of this (non-significant) advantage of long durations, in line with previous findings (Vallesi et al., 2008, 2011, 2014). Our participants may have adopted a specific strategy to discriminate between shorter and longer durations compared to the reference duration, as suggested by higher NEs for the 300 ms target duration than those appearing for the 500 ms target duration. Finally, we found a reversed Simon-like effect with better performance with the down key when the reference stimulus was presented at the top of the screen, and better performance with the up key when the reference stimulus was presented at the bottom of the screen (even if this comparison was not significant). This finding may be in line with the higher number of participants with a reversed STEARC effect, reducing the reliability of the regression analysis. On one hand, it is possible that the presentation of the reference stimulus along the vertical axis could have induced a typical reading pattern from top to bottom, thus explaining the interaction between Response Position and Stimulus Location. We hypothesize that these observed data could resemble a general scanning habit of reading and writing from top to bottom, inducing a top-to-bottom time representation. In a speculative way, our interaction could resemble the findings reported by Casasanto and Bottini (2014b), who described both a downward and an upward timeline when participants were exposed to downward (i.e., words were rotated 90° and were read from the top to the bottom of the screen) and upward (i.e., words were rotated 90° and were read from the bottom to the top of the screen) orthography, respectively. In line with these findings, our two-way interaction could indicate that the spatial location of the reference stimulus induced (or influenced) the downward or upward scanning processing. On the other hand, the weakness of the STEARC effect could be explained by the difference between experiments, as suggested by faster responses in Experiment 2 compared to Experiment 1. The longer mean RTs for Experiment 1 could explain the stronger STEARC effect in this experiment given that we observed that the STEARC effect arose for longer response durations. Thus, general faster responses found in Experiment 2 could weaken the STEARC effect. However, when the regression coefficients of both experiments were compared, we did not find a significant difference, suggesting that an additional explanation was possible. Indeed, we can advance the idea that the unpredictable spatial position of the target stimulus resulted in additional (attentive) time for participants to locate the object on the screen and then process it, in order to perform the task. Conversely, in Experiment 2, the constant central position of the target may have reduced the RTs because participants had to estimate its temporal duration only. In other words, it was probable that participants had all relevant information already prior to the presentation of the (always identical) reference that started RT measurement.

4. GENERAL DISCUSSION

The present study was aimed at investigating the vertical STEARC effect using a more basic representation of time (milliseconds), with stimuli presented along the vertical axis. The vertical space was also provided by up and down response buttons on the keyboard.

The results of both experiments showed a vertical STEARC effect with associations between short durations and a “down” response key and between long durations and an “up” response key, suggesting a bottom-to-top time representation. Our results can be interpreted according to the metaphor “more is up” (Fischer, 2012; Gevers et al., 2006; Hartmann et al., 2012; Lakoff, 1987; Lakoff & Johnson, 1999). These vertical spatial-temporal associations probably reflect human experience with the physical world in which magnitude is often associated with higher space in the vertical dimension.

Considering that we found a similar STEARC effect in both experiments, and that our general STEARC effect tended to be more pronounced for slower responses in a similar way to what has been reported for the SNARC effect (Wood et al., 2008), we speculate that “groundedness” factors could account for our results, in line with the metaphor "more is up" (Fischer, 2012; Myachykov et al., 2014). As reported by Woodin and Winter (2018), verticality is associated with quantity, probably reflecting a concrete sensorimotor experience with the physical world (Hartmann et al., 2012; Lakoff & Johnson, 1980; Santiago et al., 2011). Considering that in the present study we used temporal durations instead of temporal concepts (e.g., past/future or early/later as used by Casasanto & Bottini, 2014b, Hartmann & Mast, 2012) as crucial time information, the vertical spatial-temporal association reported here could suggest that longer time corresponds to more time, along a bottom-to-top time representation. In other words, the definition of time as a duration in milliseconds could induce a more pronounced magnitude representation and thus time in the present study was, more probably, managed as a quantity, in a similar way to other quantities such as numbers, brightness, weight, and so on (Chang & Cho, 2015; Dalmaso & Vicovaro, 2019; Fumarola et al., 2014; Gevers et al., 2003, 2004), in line with the existence of a general mechanism for magnitude processing (Bueti & Walsh, 2009; Cohen Kadosh et al., 2007, 2008; Fabbri et al., 2012; Lourenco & Longo, 2010; Walsh, 2003, 2015). The ATOM model assumes that space, time and other quantities rely upon a generalized magnitude system that computes representations such as "less than-more than", "shorter-longer", or "slower-faster", concepts that are useful for action. Furthermore, the temporal estimation task used here explicitly required participants to classify shorter (less than) or longer (more than) durations with respect to a fixed middle duration. In other words, in addition to the use of visual stimuli along the vertical dimension and vertically displayed response keys, the type of temporal information and explicit temporal (magnitude) task could be factors that contribute to explaining our findings of a vertical STEARC effect according to the metaphor "more is up" (compared to the null results in previous studies). These assumptions are further supported by the distance effect found in both experiments for RTs and NEs. The distance effect (Di Bono et al., 2012; Dormal et al., 2006; Fabbri et al., 2012; Santiago et al., 2010; Vallesi et al., 2008) suggests that a temporal magnitude was placed on a vertical MTL, after which further processing could proceed, in line with the distance effect found with different magnitudes (Bruzzi et al., 2017; Cohen Kadosh & Henik, 2006; Dalmasio & Vicario, 2019; Dehaene et al., 1993; Fulbright et al., 2003; Fumarola et al., 2014; Gevers et al., 2003, 2004; Pinel et al., 2004; Rusconi et al., 2006; Sellaro et al., 2015; Verguts & Van Opstal, 2005). The similarity of both STEARC and distance effects between the present study and the studies provided by Fabbri et al. (2013a,b) with the same methodology along the horizontal axis could indicate that it is possible to access temporal magnitude immediately along both axes. However, future studies are needed to determine whether the vertical representation of time (and probably the explanation based on the more-is-up metaphor) is related to quantity/duration or is also extended to other temporal concepts, such as past/future or early/later, given that previous studies have found that the future, at least, has been related to the upper space (Hartmann et al., 2014; Leone et al., 2018; Ruiz Fernandéz et al., 2014; Stocker et al., 2016). In addition, in neither of the studies was a size effect found, implying a dissociation between distance and size effects, as found with numbers (Verguts & Van Opstal, 2005). This dissociation could advocate the involvement of different mechanisms, as well as that of different models, in the mental representation of time. Thus, future studies should examine the dissociation between distance and size effects, and conduct an investigation, similar to that concerning the numerical domain, into the possible sources of these effects (Krajcsi, 2017).

Considering that our results could be consistent with the idea of a spatially coded representation of time (Fabbri et al., 2013a,b; Ishihara et al., 2008; Vallesi et al., 2008), it is important to take into account alternative interpretations. According to the polarity account (Proctor & Cho, 2006), short and down could be associate with a negative polarity whereas long and up could be associated with a positive polarity. Since temporal (short/long) and spatial (down/up, in our study) features of response buttons are coded in bipolar dimensions, and since those corresponding polarities induced a faster response selection, our correspondence between short-down and long-up could explain the STEARC effect. Nevertheless, Santiago and Lakens (2015) did not reconcile with the polarity correspondence explanation for horizontal SNARC and STEARC effects. Indeed, in this study, the authors reported, in a series of experiments, that spatial-numerical and spatial-temporal associations were not significantly modulated by response eccentricity as a lateral displacement of the response device. Specifically, Santiago and Lakens (2015) failed to replicate a typical performance reported by the polarity correspondence with numbers and time, in terms of the up-right or up-left advantage in an orthogonal Simon task (e.g., stimuli presented above or below a fixation point and responses performed using left and right keys) when the response device is placed to the right or to the left of the screen, respectively (Proctor & Cho, 2006).

An alternative explanation is provided by the dual-route cognitive model: we found an increase in the STEARC effect with increased response latencies (Figure 4), as predicted by this model (Gevers et al., 2006). The role played by conditional and unconditional routes in motor response may explain our results because the spatial information along the vertical dimension discriminated between the up and down responses. In line with the (vertical) SNARC effect (Gevers et al., 2006; Hartmann et al., 2014; Ito & Hatta, 2004; Müller & Schwarz, 2007; Schwarz & Keus, 2004; Shaki & Fischer, 2012), in the present study we report that the congruent situations (i.e., down-short and up-long) brought faster responses; both routes led to the same stimulus-response associations. In incongruent situations (i.e., down-long and up-short), the two routes activate different stimulus-response associations, given that the correct response was activated in the conditional route whereas the concurrent response was activated in the unconditional route. However, other interpretations could be taken into account (e.g., Flexible Foundations View proposed by Santiago et al., 2011), given that van Dijck and Fias (2011), for example, provided an explanation for SNARC-related phenomena. Further studies are needed to address which accounts could explain the vertical space-time interaction.

Probably, the most critical point is related to the 2-D meaning of verticality adopted in the present study, with two response keys displayed on horizontal plane. With this spatial arrangement, the response keys could resemble a radial plane (near-far; Winter et al., 2015a). In any case, we believe that several pieces of evidence challenge the possibility that we found a radial STEARC effect due to the horizontal position of the keyboard, and the response keys that resemble an anterior and posterior position (Hartmann et al., 2014). Firstly, our "down" (2) or "up" (8) response keys on the keyboard could be equivalent to the vertical dimension of response buttons used in previous studies assessing verticality in several SNARC-like effects (Gevers et al., 2006; Ito & Hatta, 2004; Müller & Schwarz, 2007; Shaki & Fischer, 2012; Vu et al. 2000). Secondly, the task instructions underlined the fact that the response keys were "down" (2) or "up" (8) on the keyboard, as demonstrated by all of the participants' reports during their debriefing session, in which participants stated that they interpreted the keys as being vertically related to each other (instead of perceiving a radial relationship between keys), even though the keys were positioned radially from one another. Thirdly, in both experiments the spatial and visual manipulations enhanced vertical information more than radial information. Shaki and Fischer (2018) found horizontal and vertical SNARC effects when explicitly spatial or magnitude features are activated. In a similar way, in the present study we found a vertical STEARC effect because both spatial and temporal magnitude are activated. In order to disentangle the term "vertical", studies with true (perpendicular to the horizontal plane) vertical response keys are needed. In a similar way, future studies should address the issue of radial orientation to disambiguate between a vertical and radial mapping of time representation.

Another point is related to the demonstration that temporal durations are represented in extracorporal space, where the spatial down-top position and not the bodily (left-right hands) effector played a crucial role, in a similar manner to the representation of numbers (Dehaene et al., 1993; Hartmann et al., 2014). In similar way to what has been reported by Müller and Schwarz (2007), the impact of effector side disappeared when instructions more strongly emphasized the vertical dimension of the response buttons (see also Ito & Hatta, 2004), confirming that a constant hand-to-button mapping (varied as a between-subjects factor) is necessary in order for an interaction to appear between space and time processing along the vertical axis. However, the Group x Duration interaction on NEs of Experiment 2 and the Group x Duration x Stimulus Location interaction on RTs of the omnibus ANOVA could indicate that hand-key assignment plays a role in spatial-temporal association. Future studies should disambiguate between embodied and disembodied aspects of the mental representation of time (e.g., Fischer, 2012).

To sum up, the present study demonstrates a vertical representation of time with short durations related to the down key and long durations related to the up key, in a similar way to that of other magnitudes, such as numbers (e.g., Winter et al., 2015b) or loudness (e.g., Bruzzi et al., 2017); this supports the notion that the STEARC effect could be the manifestation of a more general mechanism devoted to the processing of magnitude, with the computation of representations such as "*less than-more than*". According to the proponents of Conceptual Metaphor Theory (Lakoff & Johnson, 1980, 1999) and embodied cognition more generally (e.g., Barsalou, 2008), it has been emphasized that time, an abstract concept, may be grounded in terms of a concrete concept such as space. Specifically, the more-is-up metaphor could explain the bottom-to-top time representation that is due to a direct experience in interaction with the world (Lakoff & Johnson, 1980, 1999), suggesting an experienced correlation between height and amount of substance. Contrary to the contradictory results of a vertical representation of time defined as past/future (D-time) or earlier/later (S-time), the present study clearly demonstrates, for the first time, a vertical spatial representation of T-span. Future studies should assess the level at which the space-time congruency effect emerges within the cognitive system.

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