The Mechanisms of Space-Time Association: Comparing Motor and Perceptual Contributions in Time Reproduction

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Abstract

The spatial-temporal association indicates that time is represented spatially along a left-to-right line. It is unclear whether the spatial-temporal association is mainly related to a perceptual or a motor component. In addition, the spatial-temporal association is not consistently found using a time reproduction task. Our rationale for this finding is that, classically, a non-lateralized button for performing the task has been used. Using two lateralized response buttons, the aim of the study was to find a spatial-temporal association in a time reproduction task. To account for the perceptual component, reference and target stimuli were presented in different spaces through four experiments. In all experiments, a Spatial-Temporal Association of Response Codes (STEARC) effect was found and this effect was not modulated by the spatial position of both reference and target stimuli. The results suggested that the spatial-temporal association was mainly derived from the spatial information provided by response buttons, reflecting a motor but not visuospatial influence.

Keywords: STEARC effect; Spatial processing; Temporal reproduction task

1. Introduction

Despite the increasing knowledge of the anatomical basis of time processing (e.g., Ivry & Spencer, 2004; Koch, Oliveri & Caltagirone, 2009), there is relatively little in the literature on how the cognitive system represents such an elusive concept as time. Cognitive representation of time is likely to be at least partially visuospatial in nature. According to

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the Conceptual Metaphor Theory, time is associated more with concrete domains, such as space (Lakoff & Johnson, 1980, 1999). Although the horizontal back-front mapping constitutes the most productive way to project space onto time (for a review see, Radden, 2004), in recent years it has been found that time is represented spatially along a left-right mapping (Oliveri, Koch & Caltaghirone, 2009a).

A possible determinant of this time directionality is constituted by the words used in a given language to describe time. English and Mandarin Chinese speakers, for instance, speak about time horizontally and vertically, respectively. This linguistic habit seems to automatically activate different culturally specific spatial representations (i.e., horizontal for English speakers and vertical for Mandarin speakers) when reasoning about time (Boroditsky, 2001; Boroditsky, Fuhrman & McCormick, 2011). Also, reading and writing systems of different cultures can influence the left-to-right spatial representation of time. Tversky, Kugelmass and Winter (1991) studied the way in which children from three linguistic groups (English, Arabic, and Hebrew) produced graphical representations of various relations, such as temporal, spatial, quantitative, and preference relations. The effect of the reading and writing system was found only when temporal concepts were represented: left-to-right was dominant for English speakers, right-to-left was dominant for Arabic speakers, with Hebrew speakers in the middle.

The metaphoric representation of time along a line oriented from left-to-right is also confirmed, observing cognitive studies (e.g., Casasanto & Boroditsky, 2008; Ishihara, Keller, Rossetti & Prinz, 2008; Ouellet, Santiago, Funes & Lupiñez, 2010; Santiago, Lupiñez, Pérez & Funes, 2007; Torralbo, Santiago & Lupiñez, 2006; Vallesi, Binns & Shallice, 2008; Weger & Pratt, 2008). Using different experimental materials, such as temporal words (Ouellet et al., 2010; Santiago et al., 2007; Torralbo et al., 2006; Weger & Pratt, 2008), foreperiod (Vallesi et al., 2008), name of actors (Weger & Pratt, 2008) or sequence of clicks (Ishihara et al., 2008), cognitive studies show an association between short durations and left space and an association between long durations and right space.

It is possible that the spatial-temporal association is related to the spatial position of stimuli. For example, Torralbo et al. (2006) asked participants to categorize words according to past-ness or future-ness (e.g., “yesterday” or “tomorrow”) which were presented in different spatial locations (i.e., in the left or right space). Responses were faster when a irrelevant word location was congruent with the left-past and right-future metaphoric mapping (see also Santiago et al., 2007 for similar results).

It has been also proposed that spatial-temporal association is linked to the spatial position of response buttons, such as in the temporal estimation task with two lateralized response buttons (Ishihara et al., 2008; Santiago et al., 2007; Torralbo et al., 2006; Vallesi et al., 2008). In this task, the participants have to judge whether the duration of a target is shorter or longer than the duration of a reference cue, pressing a left or right button according to task instruction. For example, in Ishihara et al. (2008), the participants were asked to press one of the two response keys depending on whether the timing of a given probe was earlier or later than expected based on the preceding clicks. According to the spatial position of response buttons, Ishihara et al. (2008) found a Spatial-TEmporal Association of Response Codes (STEARC) effect, suggesting that short durations were
responded to faster with the left hand, whereas the long durations were responded to faster with the right hand. In a similar way, Fabbri, Cancellieri and Natale (2012) required participants to perform a temporal estimation task (i.e., short-long) with two spatial response buttons, presenting temporal stimuli (numbers or letters) in a central position. The authors found a general STEARC effect, which was determined by the spatial positions of response keys given that the central presentation (and thus no perceptual spatial information) of stimuli.

However, Ouellet et al. (2010) not only asked participants to perform a spatial discrimination task (detecting the left or right appearance of a dot in a box) or direction discrimination task (indicating the pointing direction of left or right arrows), but also asked to indicate which temporal cue (past or future) was presented during the task. The results showed that activation of a temporal cue influenced both the orientation of spatial attention and the primed motor responses to left or right space. The authors discussed the results stating that perceptual and motor levels were independent of each other (see also Santiago et al., 2007). To reconcile these different influences of perceptual and motor levels in associating space and time, Kong and You (2011) proposed the “intermediate coding” account. In this account, the temporal stimuli were first categorized as “past” (short) or “future” (long), and then the concept of past-short or future-long activated an abstract spatial code such as “left” or “right.” According to the task characteristics, physical space or manual response codes are activated.

The STEARC effect (Ishihara et al., 2008) reflected a spatial-temporal association impacting the sensorimotor transformation process which mediated stimulus perception and response preparation. From a neuro-anatomical point of view, the parietal cortex was involved in the interaction of space and time (Koch et al., 2009). For instance, the damage to the parietal cortex caused deficits in temporal as well as spatial experience (Critchley, 1953). The relevance of parietal cortex in spatial-temporal processing has been supported by neuropsychological studies on hemispatial neglect (i.e., a syndrome characterized by a deficit in attentional processing stimuli presented to the left hemispace) patients after parietal lesion. For the first time, Basso, Nichelli, Frassinetti and di Pellegrino (1996) studied temporal perception in a right parietal patient with spatial neglect. The patient overestimated durations of stimuli presented in the leftward space of the right space and underestimated durations of stimuli presented in the non-neglected field.

Walsh (2003) argued that space, time and quantity may be computed according to a common metric and in a common neural structure (right parietal cortex) into a generalized magnitude system (A Theory of Magnitude or ATOM model, Walsh, 2003). The model proposed that time, space, and quantity are influenced by each other (for a review, see Bueti & Walsh, 2009; Fabbri & Natale, 2009). Specifically, the right parietal cortex revealed the common need for space, time, and quantity information to be used in sensorimotor transformation, suggesting the presence of a generalized magnitude system for the action. As reported by Bueti and Walsh (2009), the temporal and spatial information are usually necessary for action (e.g., reaching, pointing, or grasping). According to the ATOM model, spatial-temporal association is mainly derived from a motor component, or at least that perceptual and motor components are additive instead of independent each
other. Unfortunately, the ATOM model has been suggested in need of reviewing neuroimaging and neuro-anatomical studies. Thus, more behavioral studies are needed to assess the reliability of the model (Fabbri et al., 2012; Fabbri & Natale, 2009).

The ATOM model further suggests that the spatial-temporal association should be found in other temporal tasks, without the experimental procedure of two forced choice response buttons. In the temporal cognitive domain, the temporal reproduction task can be employed for studying time processing (Bangert, Reuter-Lorenz & Seidler, 2011; for a review, see Wearden & Lejeune, 2008). In this task, participants initially receive some sample duration, then they must reproduce it by making some motor response with the same duration. In the temporal reproduction task, individuals encode a duration and transform it into a motor program to produce the duration via movement. For temporal estimation, individuals merely compare two abstract representations of durations in memory and generate a response to indicate whether they match. These different response requirements are presumed to render the tasks more reliant on motor versus perceptual processes for timing, respectively. In both temporal estimation and reproduction tasks, a motor response is required, the difference being that the judgment of the whole interval is operationalized by a motor act (i.e., temporal judgments are based on motor representations) in the temporal reproduction task, whereas in the time estimation task (Bueti & Walsh, 2010; Bueti, Walsh, Frith & Rees, 2008; Fabbri et al., 2012; Vidal, Bonnet & Macar, 1991, 1992), it is based entirely on a perceptual judgment (i.e., temporal judgments are based on perceptual representations). The inclusion of duration as a dimension of the response may necessitate different encoding and memory processes in temporal reproduction than those engaged for temporal estimation (Lewis & Miall, 2006).

To our knowledge, the use of a temporal reproduction task in investigating the spatial-temporal interaction gives controversial results. Oliveri et al. (2009b) explored the effects of inhibitory repetitive transcranial magnetic stimulation (rTMS) trains over the (posterior) parietal cortex in healthy participants performing time reproduction. The repetitive magnetic stimulation did not affect the temporal estimation in time reproduction task either stimulating the right or the left parietal cortex. This finding was further confirmed testing right-brain damage patients with and without neglect. No group difference was shown in temporal reproduction task. However, Frassinetti, Magnani and Oliveri (2009) showed prismatic lenses effects (i.e., rightward and leftward deviations) using the temporal reproduction task. In line with these findings, Fabbri et al. (2012) demonstrated that the spatial-temporal association, indexed by the STEARC effect, could be observed in a time reproduction task, applying a repeated measures design. The participants were requested to perform the task in two sessions pressing either a right key (with the right hand) or a left key (with the left hand) instead of pressing a non-lateralized response key (which is the classical procedure). Due to the spatial information provided by the spatial locations of response keys (i.e., motor level), a STEARC effect was found in the time reproduction task, using this experimental design. However, Fabbri et al. (2012) presented the temporal stimuli in a central position, and thus no visuospatial influence was taken into account.
The purpose of this study was to test whether the spatial-temporal association was mainly influenced by perceptual or motor components and whether these components were independent each other or additive, given that in the literature this aspect was not completely clear. Applying a similar task procedure used by Fabbri et al. (2012), in a repeated measures design, the participants performed a time reproduction task, pressing a right-hand side button in one condition and a left-hand side button in the other, to stop an imaginary clock. Moreover, Fabbri et al. (2012) modified the spatial position of temporal stimuli through four experiments, assessing the visuospatial influence in spatial-temporal association. As done by Oliveri et al. (2009b), we presented a reference cue (i.e., a yellow rectangle) in the encoding phase and a target stimulus (i.e., a light-blue rectangle) in the reproduction phase. Thus, we created four different spatial conditions between reference and target stimuli. In Experiments 1 and 2, only one stimulus varied spatially along the screen while the other one remained fixed at the center position. In Experiments 3 and 4, both stimuli varied spatially.

2. Experiment 1

In Experiment 1, participants performed a temporal reproduction task with sub-seconds intervals. In particular, the reference stimulus (i.e., yellow rectangle) was always presented at the center of the screen during the encoding phase while the target stimulus (i.e., light blue rectangle) could appear in one of three spatial positions during the reproduction phase: left, center, or right side of the screen. Participants performed the task twice with two lateralized response buttons. Thus, two spatial aspects were provided: the spatial information of response buttons and of the target positions.

The interaction between the spatial position of response keys and the duration to-be-reproduced (short-long) should indicate a STEARC effect (Ishihara et al., 2008), suggesting the contribution of the motor component in associating space with time. The interaction between the spatial position of stimuli and the duration should indicate a spatial-temporal congruency effect (Santiago et al., 2007; Torralbo et al., 2006), suggesting the contribution of the perceptual component in spatial-temporal association. Finally, the triple interaction between spatial position of response keys, duration, and spatial conditions should indicate an additive effect between perceptual and motor levels in spatial-temporal association.

2.1. Method

2.1.1. Participants

Thirty-two University students (28 females) participated in this study as volunteers. The mean age was 24.19 (SD = 2.40). The participants took the Edinburgh Handedness Inventory (EHI; Oldfield, 1971). According to the EHI score, there were 29 right-handed and 3 left-handed. All participants had normal or corrected-to-normal vision. The study was conducted following local ethical guidelines.
2.1.2. Materials and procedure

In the temporal reproduction task, participants were required to reproduce the duration of a reference stimulus (i.e., yellow rectangle: 192 pixels in length × 128 pixels in height). All participants were tested individually in a quiet room. They sat facing the computer screen. The viewing distance from the computer monitor was 60 cm. Stimulus presentation and data collection were controlled using E-Prime 1.1. (Schneider, Eschman & Zuccolotto, 2002). The display had a resolution of 1,072 × 960 pixels and was refreshed at a frequency of 72 Hz. The task was repeated in two separate sessions: right key condition (in which subjects were instructed to press the “6” key of a numerical keypad on a normal keyboard with their right hand) and left key condition (the “4” key was pressed with the left hand). The numerical keypad was placed horizontally and aligned with reference to the mid-sagittal plane of the body. In this way, the left (i.e., 4 key) and the right (i.e., 6 key) keys were defined according to mid-sagittal plane of the body. The response buttons were covered by two green stickers in order to avoid any numerical influence. The order of key assignments was counterbalanced among subjects.

Similar to the procedure carried out by Oliveri et al. (2009b), a white cross (+) sign, in Courier New 120-point type, on a black background appeared at the center of the screen as a fixation point for 400 ms. Following the presentation of the fixation point, a black screen appeared for 200 ms. After that, a yellow rectangle, the reference stimulus, appeared centrally on the screen with a black background. As shown in Fig. 1, reference stimulus remained on the screen for one of five different durations: 200, 300, 400, 500, or 600 ms (encoding/estimation phase). The durations of 200 and 300 ms were considered short durations in our series of stimuli, while those of 500 and 600 ms were considered long durations in our series of stimuli. Then a black screen appeared, as an interstimulus interval (ISI). To avoid any response strategy, this black screen could last for a random interval selected from 700 to 800 ms. After this ISI, a BEEP sound was presented. The participants were instructed to reproduce the duration of the reference stimulus after the presentation of the sound (reproduction phase). The sound activated a virtual clock and the participants had to stop this clock by pressing the correct button when a similar duration had passed. Thus, the sound indicated the starting moment of reproduction phase and the key press indicated the end of the reproduction phase (see also, Bangert et al., 2011). For the short and long durations, a light-blue rectangle (the same size dimensions of the yellow rectangle) was presented all together with the sound in three spatial position. Participants were instructed to ignore this target stimulus because it was irrelevant to performing the task. The reference-target pair determined three spatial conditions: (1) center-left (C-L) condition, (2) center-center (C-C) condition, and (3) center-right (C-R) condition. The x and y coordinates for left, center, and right positions were, respectively, as follows: (a) 256 × 384 pixels, (b) 512 × 384 pixels (these coordinates were equal for yellow and blue light rectangles), and (c) 768 × 384 pixels. When the yellow rectangle lasted 400 ms in the reproduction phase, no target appeared on the screen (catch trials). The catch trials corresponded to the 33.33% of all trials. These catch trials were excluded from the analysis. In each block, 90 trials were presented in a pseudo-random order. Before the test, a training session was run with 10 trials presenting
all spatial conditions lasting 200 or 600 ms. The training phase could be performed for a second time, if requested by participants. The order of conditions was counterbalanced across subjects. After each block, individuals had the opportunity to take a 1-min break. The experiment lasted approximately 45 min.

2.1.3. Data analysis

Means of reproduction times (ReT) were calculated. The ReT was measured as the reproduction time from the onset of acoustic sound (which coincides with the virtual...
clock starting) to the key press (coincides with the virtual clock ending). A three-ways repeated measures ANOVA was carried out on ReTs, with Key (2 levels: left vs. right), Duration (2 levels: short and long) and Spatial Condition (3 levels: C-L, C-C and C-R) as within-subjects factors. The same ANOVA was also performed on accuracy index (AI), defined by the ratio between mean (subjective) reproduced durations and the reference durations for each subject in each condition. Thus, values equal to 1 indicated a good performance, while values above 1 indicated an overestimation and values below 1 indicated an underestimation. When a reliable significance was found, the Scheffé post hoc test was run. Values with \( p < .05 \) were considered significant.

### 2.2. Results and discussion

The average of ReTs was 570 ms \((SD = 64.80 \text{ ms})\). In Table 1 there are the mean ReTs for each condition. The ANOVA on ReTs revealed no significant main effects. The Spatial Condition factor tended toward the significance \([F(2,62) = 3.11, MSe = 2595.26, \eta^2_p = 0.09, p = .052]\), indicating that the C-C condition (560 ms; \(SD = 79.74 \text{ ms}\)) induced higher ReTs compared to C-L (548 ms; \(SD = 78.91 \text{ ms}\)) and C-R (545 ms; \(SD = 80.32 \text{ ms}\)) conditions. Importantly, the interaction Key \(\times\) Duration was significant indicating a STEARC effect \([F(1,31) = 19.38, MSe = 2573.30, \eta^2_p = 0.38, p < .0001]\). At the Scheffé test, the right key (539 ms; \(SD = 86.85 \text{ ms}\)) determined lower ReTs than the left key (565 ms; \(SD = 75.71 \text{ ms}\)) for long durations with \( p < .05 \). Although the comparison was not significant, the left key (540 ms; \(SD = 75.20 \text{ ms}\)) determined lower ReTs than the right key (559 ms; \(SD = 80.87 \text{ ms}\)) for reproducing short durations. No other interactions reached significant levels \((Fs < 2.10 \text{ with } ps \text{ ranging from .14 to .33})\).

The average of AIs was 1.63 \((SD = 0.17)\) indicating a general overestimation. In Table 1, there are the mean AIs for each condition. The ANOVA on AIs showed a significant Duration effect \([F(1,31) = 1091, MSe = 0.145334, \eta^2_p = 0.97, p < .00001]\) reflecting an overestimation for the short durations (2.30; \(SD = 0.32\)) while long durations (1.01; \(SD = 0.15\)) were correctly reproduced, which is partially in agreement with the Vierordt’s law (Vierordt, 1868; i.e., subjects overestimated short durations and underestimated long durations; see also the “migration effect” in Malapani, Deweer & Gibbon, 2002). A Spatial Condition effect was also found, \(F(2,62) = 4.07, MSe = 0.020600, \eta^2_p = 0.12,\)

<table>
<thead>
<tr>
<th>ReTs</th>
<th>C-L</th>
<th>C-C</th>
<th>C-R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short durations Left key</td>
<td>529 (69.21)</td>
<td>551 (62.89)</td>
<td>541 (93.49)</td>
</tr>
<tr>
<td>Right key</td>
<td>551 (76.60)</td>
<td>568 (88.02)</td>
<td>559 (78.00)</td>
</tr>
<tr>
<td>Long durations Left key</td>
<td>572 (62.89)</td>
<td>562 (76.76)</td>
<td>561 (87.49)</td>
</tr>
<tr>
<td>Right key</td>
<td>540 (106.96)</td>
<td>558 (91.28)</td>
<td>518 (62.31)</td>
</tr>
<tr>
<td>AIs</td>
<td>C-L</td>
<td>C-C</td>
<td>C-R</td>
</tr>
<tr>
<td>-----</td>
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</tr>
<tr>
<td>Short durations Left key</td>
<td>2.20 (0.28)</td>
<td>2.30 (0.27)</td>
<td>2.27 (0.39)</td>
</tr>
<tr>
<td>Right key</td>
<td>2.30 (0.31)</td>
<td>2.38 (0.36)</td>
<td>2.33 (0.33)</td>
</tr>
<tr>
<td>Long durations Left key</td>
<td>1.05 (0.11)</td>
<td>1.03 (0.14)</td>
<td>1.03 (0.16)</td>
</tr>
<tr>
<td>Right key</td>
<td>0.99 (0.19)</td>
<td>1.02 (0.17)</td>
<td>0.95 (0.11)</td>
</tr>
</tbody>
</table>
At the post hoc test, the C-C condition (1.68; $SD = 0.23$) determined a higher overestimation compared to C-L (1.63; $SD = 0.22$) and C-R (1.64; $SD = 0.25$) conditions ($p < .05$ for both comparisons). Importantly, the interaction Key $\times$ Duration remained reliable with AIs [$F(1,31) = 20.52$, $MSe = 0.019668$, $\eta^2_p = 0.40$, $p < .00001$]. The post hoc test revealed a lower overestimation for the left key (2.26; $SD = 0.31$) than the right key (2.34; $SD = 0.33$) when short durations were reproduced ($p < .05$). For the right key (0.99; $SD = 0.16$), there was lower overestimation than the left key (1.04; $SD = 0.14$) when long durations were reproduced, but this comparison was not significant. No other interactions were reliable ($Fs < 2.95$ with $ps$ ranging from .06 to .64).

On the whole, results showed a STEARC effect (Fabbri et al., 2012; Ishihara et al., 2008), confirming the associations between the left space (i.e., left key) and short durations, and between the right space (i.e., right key) and long durations (Vallesi et al., 2008) in performing a temporal reproduction task. The STEARC effect revealed that the spatial-temporal association was more related to the motor component, given that no spatial-temporal congruity effect was found. This finding suggested that the perceptual and motor components were independent each other (Ouellet et al., 2010; Santiago et al., 2007).

However, a spatial condition effect (i.e., C-L, C-C and C-R) was found in the reproduction performance, especially for AI. Performance was influenced by the spatial position of the target. This finding could indicate that the (irrelevant) spatial position of the target was processed, while the temporal duration was reproduced. In that way, the spatial information of the target position could facilitate the temporal reproduction according to the left-to-right time line. The motor component of reproduction task probably masked or reduced the influence of perceptual component. In line with this assumption, no triple interaction was found and thus no additive effect of perceptual and motor components was reliable.

The lack of this additive effect could be related to the fact that the reference rectangle appeared in all trails in the center position. It is worth noting that the reference stimulus was relevant for the task because its duration had to be reproduced. In Experiment 2, the spatial position of yellow rectangle was modified while the subsequent (irrelevant) light blue rectangle remained fixed in the central position.

### 3. Experiment 2

In Experiment 2, the participants performed the aforementioned reproduction task, this time the difference being that the yellow rectangle (i.e., reference stimulus) could appear in the three spatial positions of the screen, while the subsequent (irrelevant) light blue rectangle appeared on the screen centrally.

The interaction between spatial position of response keys and duration should indicate a STEARC effect (motor component). The interaction between the spatial position of stimuli and the duration should indicate a spatial-temporal congruency effect (perceptual component). The triple interaction between the spatial position of the response keys, the
duration to-be-reproduced and the spatial conditions should indicate an additive effect between perceptual and motor levels in spatial-temporal association.

3.1. Method

3.1.1. Participants
Twenty-four University students (16 females) participated in this study as volunteers. The mean age was 26.29 (SD = 6.37). There were 20 right-handed and 4 left-handed, according to the EHI (Oldfield, 1971). All participants had normal or corrected-to-normal vision. The study was conducted following local ethical guidelines.

3.1.2. Materials and procedure
The materials and procedure were the same as in Experiment 1 with the following exception (Fig. 1). The reference-target pair determined three spatial conditions, respectively: (a) left-center (L-C) condition, (b) center-center (C-C) condition, and (c) right-center (R-C) condition. The x and y coordinates for left, center, and right positions were the same of Experiment 1.

3.1.3. Data analysis
Means of ReT were calculated, as in Experiment 1. A three-ways repeated measures ANOVA was carried out on ReTs, with Key (2 levels: left vs. right), Duration (2 levels: short and long), and Spatial Condition (3 levels: C-L, C-C and C-R) as within-subject factors. The same ANOVA was also performed on AI, defined as in Experiment 1. When a reliable significance was found, the Scheffé post hoc test was run. Values with \( p < .05 \) were considered significant.

3.2. Results and discussion
The average of ReTs was 562 ms (SD = 65.51 ms). In Table 2, there are the mean ReTs for each condition. The ANOVA on ReTs revealed no significant main effects

<table>
<thead>
<tr>
<th>Spatial Condition</th>
<th>ReTs (L-C)</th>
<th>ReTs (C-C)</th>
<th>ReTs (R-C)</th>
<th>AI (L-C)</th>
<th>AI (C-C)</th>
<th>AI (R-C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short durations</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Left key</td>
<td>522 (100.56)</td>
<td>561 (93.36)</td>
<td>527 (100.16)</td>
<td>2.17 (0.42)</td>
<td>2.34 (0.36)</td>
<td>2.21 (0.44)</td>
</tr>
<tr>
<td>Right key</td>
<td>548 (85.15)</td>
<td>555 (102.55)</td>
<td>542 (105.99)</td>
<td>2.30 (0.34)</td>
<td>2.31 (0.44)</td>
<td>2.27 (0.46)</td>
</tr>
<tr>
<td>Long durations</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left key</td>
<td>548 (92.86)</td>
<td>574 (122.94)</td>
<td>548 (94.69)</td>
<td>1.00 (0.17)</td>
<td>1.05 (0.23)</td>
<td>1.00 (0.17)</td>
</tr>
<tr>
<td>Right key</td>
<td>523 (117.13)</td>
<td>544 (135.91)</td>
<td>510 (112.98)</td>
<td>0.96 (0.22)</td>
<td>0.99 (0.25)</td>
<td>0.93 (0.21)</td>
</tr>
</tbody>
</table>
Importantly, the interaction Key × Duration was significant, indicating a STEARC effect \( F(1,23) = 6.38, MSe = 5134.51, \eta^2_p = 0.22, p < .05 \). At the Scheffé test, no significant comparisons were shown. Observing the mean ReTs, for long durations the right key (525 ms; \( SD = 122.01 \) ms) determined lower ReTs compared to the left key (556 ms; \( SD = 103.50 \) ms). The opposite pattern was observed for short durations, with lower ReTs with the left key (537 ms; \( SD = 98.03 \) ms) respect to the right key (548 ms; \( SD = 97.90 \) ms). No other interactions reached significant levels \( (Fs < 1.00 \) with \( ps \) ranging from .79 to .95).

The average of AIs was 1.60 \( (SD = 0.16) \), indicating a general overestimation. In Table 2, there are the mean AIs for each condition. The ANOVA on AIs showed a significant Duration effect \( F(1,23) = 919.35, MSe = 0.127855, \eta^2_p = 0.98, p < .00001 \) reflecting an overestimation for the short durations (2.27; \( SD = 0.41 \)) and little underestimation for long duration (0.99; \( SD = 0.21 \)), which is partially in agreement with the Vierordt’s law. No other main effects were found. Importantly, the Key × Duration interaction remained reliable with AIs \( F(1,23) = 4.30, MSe = 0.047954, \eta^2_p = 0.16, p < .05 \). Even though the comparison was not significant, when short durations were reproduced, a lower overestimation for the left key (2.24; \( SD = 0.41 \)) than the right key (2.29; \( SD = 0.41 \)) was shown. At the same time, the right key (0.96; \( SD = 0.23 \)) determined an underestimation with respect to the left key (1.02; \( SD = 0.19 \)) when long durations were reproduced. No other interactions were reliable \( (Fs < 0.50 \) with \( ps \) ranging from .62 to .86).

Results of both reproduction time and accuracy mirrored those of Experiment 1. In a temporal reproduction task, the STEARC effect was found (Fabbri et al., 2012; Ishihara et al., 2008), probably reflecting an activation of a mental time line in which short durations were represented on the left side while long durations were represented on the right side (Vallesi et al., 2008). As in Experiment 1, the motor component was mainly linked to the spatial-temporal association given that no spatial-temporal congruency or additive effect was reliable.

In this experiment, the spatial conditions (i.e., L-C, C-C, and R-C) were determined to add spatial relevance to the relevant temporal stimulus which was the yellow rectangle (cue). However, the spatial conditions did not influence the performance. The lack of this spatial condition effect could indicate that the spatial-temporal association was probably independent from the perceptual spatial processing.

In the Experiment 3, we presented the yellow and light blue rectangles in opposite spatial position. For example, when the yellow rectangle appeared in the left position the following light blue rectangle appeared in the right position. The reversed situation (yellow rectangle in the right and light blue rectangle in the left spaces) was also presented. In other words, in this Experiment 3, we maximized the spatial information between visual stimuli creating a “movement” between the spatial positions of reference and subsequent (target) stimuli. Using the same spatial manipulation between reference and target stimuli, underestimation (movement from right-to-left space) and overestimation (movement from left-to-right space) were found in a temporal estimation task (Vicario et al., 2008).
4. Experiment 3

In the Experiment 3, the participants performed the aforementioned reproduction task, the only difference being that the yellow and light blue rectangles appeared in opposite spatial position of the screen. The STEARC effect should indicate a motor influence while the spatial-temporal congruency effect should indicate a perceptual influence in spatial-temporal association. A modulation of STEARC effect according to spatial conditions should indicate an additive effect between perceptual and motor components.

4.1. Method

4.1.1. Participants

Eighteen University students (12 females) participated in this study as volunteers. The mean age was 25.72 (SD = 7.59). There were 16 right-handed and 2 left-handed, according to the EHI score (Oldfield, 1971). All participants had normal or corrected-to-normal vision. None had participated in previous Experiments. The study was conducted following local ethical guidelines.

4.1.2. Materials and procedure

Materials and procedure were the same as in previous experiments with the following exception (Fig. 1). The reference-target pair determined three spatial conditions, respectively: (a) left-right (L-R) condition, (b) center-center (C-C) condition, and (c) right-left (R-L) condition (in Fig. 1, the white arrows showed the relation between reference and target). The x and y coordinates for left, center, and right positions were the same as those used in previous experiments.

4.1.3. Data analysis

Means of ReTs were calculated. A three-ways repeated measures ANOVA was carried out on ReTs, with Key (2 levels: left vs. right), Duration (2 levels: short and long) and Spatial Condition (3 levels: L-R, C-C, and R-L) as within-subject factors. The same ANOVA was also performed on an AI. When a reliable significance was found, the Scheffé post hoc test was run. Values with $p < .05$ were considered significant.

4.2. Results and discussion

The average of ReTs was 600 ms (SD = 74.39 ms). In Table 3, there are the mean ReTs for each condition. The ANOVA on ReTs revealed a significant Spatial Condition effect [$F(2,34) = 8.92$, $MSe = 6256.28$, $\eta^2_p = 0.46$, $p < .005$]. The post hoc test showed that the C-C condition (606 ms; SD = 137.08 ms) induced higher ReTs compared to other conditions (R-L: 570 ± 117.75 ms and L-R: 552 ± 95.86 ms), with $p < .05$ and $p < .005$, respectively. The Key and Duration factors failed to be significant ($F < 1.20$, $ps$ ranging from .30 to .50). Importantly, the interaction Key × Duration was significant,
indicating a STEARC effect \[ F(1,17) = 15.33, \text{MSe} = 12671.06, \eta^2_p = 0.47, p < .005 \].

The Scheffé test revealed that there was a significant difference between the right (549 ms; \text{SD} = 111.31 ms) and the left (623 ms; \text{SD} = 121.84 ms) keys in reproducing the long durations \((p < .05)\). For short durations, the left key (543 ms; \text{SD} = 104.34 ms) produced lower ReTs with respect to the right key (590 ms; \text{SD} = 130.10 ms), but this comparison was not significant. No other interactions reached significant levels \((Fs < 1.50 with ps ranging from .24 to .91)\).

The average of AIs was 1.70 (\text{SD} = 0.20) indicating a general overestimation. In Table 3, there are the mean AIs for each condition. The ANOVA on AIs showed a significant Duration effect \[ F(1,17) = 354.08, \text{MSe} = 0.251891, \eta^2_p = 0.95, p < .00001 \] reflecting a higher overestimation for the short durations \((2.36; \text{SD} = 0.48)\) than long duration \((1.08; \text{SD} = 0.21)\). Also, a Spatial Condition effect was observed \[ F(2,34) = 7.94, \text{MSe} = 0.060865, \eta^2_p = 0.45, p < .05 \]. At post hoc test, the C-C condition \((1.81; \text{SD} = 0.41)\) determined higher AIs compared to R-L \((1.68; \text{SD} = 0.36)\) and L-R \((1.66; \text{SD} = 0.28)\) conditions \((p < .05 and p < .005, respectively)\). The Key factor did not reach any significant level \((p = .62)\). The interaction between Key and Duration was reliable \[ F(1,17) = 12.41, \text{MSe} = 0.114995, \eta^2_p = 0.42, p < .005 \]. There were no significant comparisons, but the right key \((1.01; \text{SD} = 0.20)\) obtained lower AIs respect to the left key \((1.14; \text{SD} = 0.22)\) for long duration. At the same time, the left key \((2.26; \text{SD} = 0.44)\) obtained lower AIs with respect to the right key \((2.46; \text{SD} = 0.53)\) for short durations. No other interactions were reliable \((Fs < 2.40 with ps ranging from .11 to .95)\).

As in the previous experiments, the STEARC effect was found analyzing both the ReTs and AIs \((Fabbri et al., 2012; Ishihara et al., 2008)\). This result confirmed that short durations were associated with the left space, whereas long durations were associated with the right space \((Vallesi et al., 2008)\). The STEARC effect reflected the role of the motor component in associating space and time, with no reliable influence of the spatial-temporal congruity effect or any significant modulation of STEARC effect with respect to the spatial conditions.

As in the previous experiments, a significant spatial condition (i.e., R-L, C-C, and L-R) effect was found, especially for AIs. More, the spatial position of the target
influenced the reproduction accuracy of performance. Alternately, the right-to-left (R-L condition) and left-to-right (L-R condition) movements induced less overestimation respect to the C-C condition with no movement of temporal stimuli (Vicario et al., 2008). As in Experiment 1, the motor component of reproduction task could mask or reduce the impact of perceptual influence on performance.

In the Experiment 4, we presented yellow and light blue rectangles in the same spatial position, in order to maximize the spatial information provided by visual stimuli. Thus, the perceptual component was emphasized.

5. Experiment 4

In Experiment 4, the participants performed the aforementioned reproduction task, the only difference being that the yellow and light blue rectangles appeared in the same spatial position of the screen. The STEARC effect should indicate the role of the motor component in spatial-temporal association, while the spatial-temporal congruity effect should indicate the role of the perceptual component in left-short and right-long associations. A possible Simon-like (interaction between the spatial position of response keys and the spatial conditions) effect could interfere or interact with the STEARC effect. Finally, the triple interaction between three factors should indicate additive effect between the perceptual and motor levels.

5.1. Method

5.1.1. Participants

Twenty University students (16 females) participated in this study as volunteers. The mean age was 24.60 (SD = 3.94). According to the EHI score (Oldfield, 1971), there were 15 right-handed and 5 left-handed. All participants had normal or corrected-to-normal vision. None had participated in previous Experiments. The study was conducted following local ethical guidelines.

5.1.2. Materials and procedure

The materials and procedure were the same as in Experiment 3 with the following exception (Fig. 1). The reference-target pair determined three spatial conditions, respectively: (a) left-left (L-L) condition, or (b) center-center (C-C) condition, or (c) right-right (R-R) condition (in Fig. 1 the white arrows showed the relation between reference and target). The x and y coordinates for left, center, and right positions were the same as those used in Experiment 3.

5.1.3. Data analysis

Means of ReT were calculated. A three-ways repeated measures ANOVA was carried out on ReTs, with Key (2 levels: left vs. right), Duration (2 levels: short and long) and Spatial Condition (3 levels: L-L, C-C, and R-R) as within-subject factors. The same ANOVA
was also performed on an AI. When a reliable significance was found, the Scheffé post hoc test was run. Values with $p < .05$ were considered significant.

5.2. Results and discussion

The average of ReTs was 597 ms ($SD = 55.44$ ms). In Table 4, there are the mean ReTs for each condition. The ANOVA on ReTs revealed a significant Spatial Condition effect [$F(2,38) = 5.81$, $MSe = 5855.23$, $\eta^2_p = 0.40$, $p < .05$]. The post hoc test showed that the C-C condition (568 ms; $SD = 93.17$ ms) induced lower ReTs compared to other conditions (L-L: $606 \pm 99.19$ ms and R-R: $600 \pm 111.47$ ms), with $p < .05$ for both comparisons. The Key and Duration factors failed to be significant ($F < 0.20$, $ps$ ranging from .68 to .90). Importantly, the interaction Key x Duration was significant indicating a STEARC effect [$F(1,19) = 12.66$, $MSe = 6485.05$, $\eta^2_p = 0.40$, $p < .005$]. The Scheffé test revealed no significant comparisons. Observing the mean ReTs, for long durations the right key (577 ms; $SD = 107.60$ ms) determined lower ReTs compared to the left key (612 ms; $SD = 103.35$ ms). The opposite pattern was observed for short durations, with lower ReTs with the left key (568 ms; $SD = 106.78$ ms) compared to the right key (607 ms; $SD = 87.38$ ms). No other interactions reached significant levels ($Fs < 1.10$ with $ps$ ranging from .37 to .56).

The average of AIs was 1.49 ($SD = 0.14$) indicating a general overestimation. In Table 4, there are the mean AIs for each condition. The ANOVA on AIs showed a significant Duration effect [$F(1,19) = 539.87$, $MSe = 0.208242$, $\eta^2_p = 0.97$, $p < .00001$] reflecting an higher overestimation for the short durations (2.46; $SD = 0.41$) than long durations (1.09; $SD = 0.19$). Also, a Spatial Condition effect was observed [$F(2,38) = 4.05$, $MSe = 0.054742$, $\eta^2_p = 0.25$, $p < .05$]. At post hoc test, only the comparison between C-C (1.72; $SD = 0.27$) and L-L (1.81; $SD = 0.30$) conditions was reliable ($p < .05$). The Key factor did not reach any significant level ($p = .07$). The interaction between Key and Duration was reliable [$F(1,19) = 18.01$, $MSe = 0.052804$, $\eta^2_p = 0.49$, $p < .0005$]. The Scheffé test showed that, for short durations the left key (2.37; $SD = 0.45$) induced lower AIs compared to the right key (2.56; $SD = 0.37$), with $p < .05$. A lower overestimation

| Table 4 | ReTs (plus their $SD$) and AIs (plus their $SD$) in Experiment 4 for short and long durations according to each spatial condition |
|---|---|---|---|---|---|---|---|
| | L-L | C-C | R-R | L-L | C-C | R-R |
| **Short durations** | | | | | | |
| Left key | 589 (143.17) | 537 (80.26) | 580 (96.90) | 2.45 (0.61) | 2.23 (0.34) | 2.42 (0.41) |
| Right key | 606 (64.53) | 611 (94.42) | 603 (103.18) | 2.55 (0.27) | 2.57 (0.39) | 2.54 (0.44) |
| **Long durations** | | | | | | |
| Left key | 628 (101.19) | 574 (90.55) | 636 (118.30) | 1.15 (0.18) | 1.05 (0.17) | 1.16 (0.22) |
| Right key | 602 (87.87) | 549 (107.44) | 579 (127.49) | 1.11 (0.16) | 1.01 (0.19) | 1.07 (0.23) |
for the right key (1.06; SD = 0.19) than the left key (1.12; SD = 0.19) was observed when long durations were reproduced, but this comparison was not significant. No other interactions were reliable ($F_s < 1.15$ with $p$s ranging from .34 to .99).

As in previous experiments, the STEARC effect was found analyzing the ReTs and AIs (Fabbri et al., 2012; Ishihara et al., 2008). This result confirmed the association between short durations and the left key and between long durations and the right key (Vallesi et al., 2008). Moreover, this finding confirmed that spatial-temporal association was mainly linked to the motor component (Ishihara et al., 2008; Weger & Pratt, 2008). Thus, it was plausible that the STAERC effect was related to response stage, considering that no spatial-temporal congruency or additive effects were found.

As in Experiment 3, the spatial condition (i.e., L-L, C-C, and R-R) effect was reliable, especially for AIs. However, in Experiment 4, the C-C condition determined lower overestimation (and thus better performance) compared to other two spatial conditions. In Experiment 3, the opposite accuracy pattern was found. This pattern difference could indicate that the temporal reproduction performance was better facilitated when a temporal movement between reference-target pairs was induced as in Experiment 3 than when the reference and the target stimuli coded the same spatial information as in Experiment 4. Taking into account the accuracy pattern of Experiment 4, the role of target position in explaining the spatial condition effect on reproduction performance was also reduced, supporting the idea that the temporal movement between reference and target stimuli could be a better explanation of spatial condition effect.

6. General discussion

The study aimed at investigating whether the spatial-temporal association was mainly influenced by perceptual or motor components and whether these components were independent of each other or additive, in a temporal reproduction task using a repeated measures design (Fabbri et al., 2012). Specifically, the participants were requested to reproduce the temporal duration of a yellow rectangle (reference stimulus) pressing either a right or a left key in two different sessions. During the reproducing phase, a light blue rectangle (target stimulus) could appear on the screen (Oliveri et al., 2009b). Through four experiments, the reference-target pair created several spatial conditions according to their spatial positions on the screen. Thus, we could study whether the spatial-temporal association was mainly related to the spatial information provided by temporal stimuli (the perceptual component) or by the spatial information provided by response keys (the motor component). Also, we could study whether the perceptual and motor components were independent each other (Ouellet et al., 2010; Santiago et al., 2007) or, alternatively, if they were additive (Kong & You, 2011).

The main result showed a general STEARC effect analyzing both ReTs and AIs. Although, in all experiments, our participants overestimated more short durations than long durations, as partially indicated by a Vierordt’s law (Vierordt, 1868), the STEARC effect reflected a spatial-temporal association with short durations linked to the left space...
whereas long durations were linked to the right space (Casasanto & Boroditsky, 2008; Fabbri et al., 2012; Ishihara et al., 2008; Vallesi et al., 2008). In other words, the STEARC effect could indicate that the temporal reproduction task was performed better with the left button for reproducing short durations and with the right button for reproducing long durations. This spatial-temporal association added evidence in favor of a mental time line oriented from the left to the right space (Ishihara et al., 2008; Oliveri et al., 2009a; Ouellet et al., 2010; Santiago et al., 2007; Torralbo et al., 2006; Vallesi et al., 2008; Weger & Pratt, 2008). The STEARC effect reflected an automatic activation of the mental time line and the assumption of the automaticity was based on the fact that geometric rectangles were used. In previous studies, the automaticity of the spatial-temporal association could be questioned by the presentation of temporal words and thus culture habit could induce the short-left and long-right associations (e.g., Boroditsky, 2001; Tversky et al., 1991). The STEARC effect provided a clear demonstration of the linkage between spatial and temporal representations codes, an observation that derived from a metaphoric mapping account, according to which abstract concepts, such as time, are represented in more concrete coordinates, such as space (Lakoff & Johnson, 1980, 1999).

In the absence of any spatial-temporal congruity effect (no significant interactions between duration to-be-reproduced and spatial conditions were found), the STEARC effect reflected the idea that the spatial-temporal association was related to the motor (response) level, even in a temporal reproduction task. This assumption was grounded on the fact that the STEARC effect found in all four experiments derived from the spatial information provided by the two lateralized response buttons (for similar results, see Fabbri et al., 2012), instead of using a non-lateralized central button (Oliveri et al., 2009b). To better clarify this point, the spatial codes of two lateralized response buttons seemed to induce more strongly the STEARC effect than the spatial codes of stimuli positions. Using repeated-measures design with lateralized response buttons (instead of single session with non-lateralized central button, Oliveri et al., 2009b), the spatial-temporal association was observed in temporal reproduction task, suggesting the role of the motor component. This finding extended the results by Weger and Pratt (2008), who found in a cue paradigm that the spatial-temporal association was not restricted to the processing of the target-stimulus proper, but caused a more general shift in orienting that enhanced the readiness to respond to visuospatial stimuli. However, our data did not completely exclude the contribution of perceptual components in the associating space with time. Indeed, we found a Spatial Condition effect on ReTs and AIs in Experiments 1, 3, and 4, indicating that the participants were influenced by the positions of reference-target pairs, even though these spatial localizations were totally task-irrelevant. In a recent research, Di Bono et al. (2012) showed that task-irrelevant, lateralized visuospatial primes affected auditory duration judgments. The results pointed out two associations: between short durations and left-sided primes, and between long durations and right-sided primes. Given that no manual response was provided, the spatial-temporal association found by the authors could not be ascribed to any STEARC effect (i.e., motor component here) but could be induced by the physical space codes (Di Bono et al., 2012).
Here, we asked participants to perform the task twice, pressing a right key in one block and pressing a left key in the other block. This experimental procedure could probably maximize the stimulus-response congruency between the mental representation of durations along the time line and the spatial location of the response buttons (Fabbri et al., 2012; Ishihara et al., 2008; Vallesi et al., 2008). As noted by Kong and You (2011), “task characteristics have an important impact on the use of mental strategy” (p. 86): when manual responses are involved in the task, the left-right spatial codes will activate manual response codes. In temporal reproduction task, where temporal judgments are more based on motor than perceptual representations (Bueti & Walsh, 2010; Bueti et al., 2008; Fabbri et al., 2012; Vidal et al., 1991, 1992), the motor components seem to mask (or reduce) the contribution of perceptual components, when manual responses and physical spatial codes are involved in the task at the same time.

The stimulus-response congruency found here could be in line with Proctor and Cho’s (2006) polarity account, according to which salient stimulus features are mapped onto salient response codes. The STEARC effect could be considered an instance of a polarity correspondence principle, assuming that time [short (−) and long (+)] and response [left (−) and right (+)] are coded on a bipolar dimension and that corresponding polarities induce a faster response selection (Proctor & Cho, 2006). Thus, the STEARC effect may be due to the polarity correspondence between durations and responses. Although such interpretation is possible, we think that the observed pattern could be modulated by culture influence (Boroditsky, 2001; Boroditsky et al., 2011; Tversky et al., 1991).

The finding of the STEARC effect in a temporal reproduction task could be discussed, considering the role of the parietal cortex in integrating space and time. As pointed out by Bueti and Walsh (2009), the (right) parietal cortex “is equipped with an analogue system for action that computes “more than-less than,” “faster-slower,” “nearer-farther,” “bigger-smaller,” and it is on these abilities that discrete numerical abilities hitched an evolutionary ride” (p. 1832). According to the ATOM model, in the right parietal cortex several types of information are processed, including spatial, temporal, and quantity information (Walsh, 2003). This cortex plays a role in a sensorimotor transformation and it can be considered as a generalized magnitude system for action. This sensorimotor transformation mainly depends on parieto-frontal circuits, which transform sensory information into action (Rizzolatti, Luppino & Matelli, 1998). It is worth noting that both parietal and frontal areas play a role in time perception (see also, Ivry & Spencer, 2004), and, thus, damage to these parieto-frontal circuits can produce temporal representational deficits as shown by neglect patients (e.g., Basso et al., 1996). In a recent neuropsychological study, a significant correlation was found between Brodmann areas 45 (frontal area) and 39 (parietal area) and the temporal production deficit in neglect patients (Oliveri, Magnani, Filipelli, Avanzi & Frassinetti, 2012). For instance, Miles, Betka, Pendry and Macrae (2010) showed that when participants were instructed to process information pertaining to the past or future their movements were drawn toward the left or right, indicating that the processing of temporal information was revealed in patterns of action, according to the ATOM model (Walsh, 2003).
The ATOM model predicts a spatial-numerical association, indexed by the SNARC (Spatial-Numerical Association of Response Codes; e.g., Dehaene, Bossini & Giraux, 1993) effect, suggesting that small numbers are associated with the left space whereas large numbers are associated with the right space, along a left-to-right number line. The SNARC effect is discussed according to a spatial stimulus-response compatibility (e.g., Hommel & Prinz, 1997) between the internal spatial representation of numbers and the corresponding response location in the space (Dehaene et al., 1993), in a similar way to STEARC effect (Casasanto & Boroditsky, 2008; Vallesi et al., 2008). For this study, psychological studies reported that the SNARC effect was resolved at the response-related stage, but not during the later response execution processes (Gevers, Ratinckx, De Baene & Fias, 2006a; Keus, Jenks & Schwarz, 2005), especially when response selection mechanisms were involved in forced choice task. Given the phenomenological similarity between STEARC and SNARC effects (Agrillo, Ranpura & Butterworth, 2010), the role of motor/response component in spatial-temporal association was expected (Ishihara et al., 2008). Thus, the computational model of the SNARC effect developed by Gevers and colleagues (see Fig. 1 in Gevers, Verguts, Reynvoet, Caessens & Fias, 2006b, p. 33) should also be adopted for the STEARC effect, the positing of three layers representing the mental time line (bottom level), the categorization of temporal durations as short or long (middle layer), and finally, the response layers where the manual responses are spatially coded. According to this model, we speculate that in our temporal reproduction task, the mental time line is activated to estimate the duration, which is further categorized as short or long, and, finally, the left-right spatial codes of manual responses should influence the task performance. Future research is needed to develop this point.

When a forced choice task (i.e., time estimation task) is employed, the STEARC (and/or SNARC) effect is essentially measured by how much more efficiently responses can be planned and produced according to congruent (e.g., short durations and left key or small magnitude and left key) or incongruent (e.g., short durations and right key or small magnitude and right key) situations (see Dehaene et al., 1993; Fabbri et al., 2012; Ishihara et al., 2008; Keus et al., 2005). Thus, these effects are associated with a response selection and/or motor programming. The time reproduction task not only hinges on the response-related stage but also on response execution, given that a motor response is required to reproduce an estimated duration (Bueti et al., 2008). However, in the time reproduction task, an activation of the right and left parietal cortices has been found, with a stronger activation in the right parietal cortex (Bueti et al., 2008). The right parietal cortex uses representational systems, perhaps spatially encoded, which are common to time, space, and quantity as relevant to action, and this representation is available to left hemisphere areas required for action selection and generation (Bueti & Walsh, 2009; Walsh, 2003). The choice of two lateralized response buttons in our temporal reproduction task could induce a stronger activation of the right parietal cortex resulting from the STEARC (and/or SNARC) effect.

In line with this assumption, Frassinetti et al. (2009) found a temporal underestimation and overestimation after prismatic deviation in the temporal reproduction task (see also Oliveri et al., 2009b). Similarly, Basso et al. (1996) found that a neglect patient overestimated
a stimulus duration at neglected locations. This result in the healthy and neglect patients
claim of the involvement of the parietal cortex in integrating spatial (attention) and tem-
poral information (Koch et al., 2009).

Analyzing the AIs, a spatial condition effect was found according to every experimen-
tal manipulation. In Experiment 1, higher AIs were found for C-C condition compared to
other C-L and C-R conditions, whereas in Experiment 2 (with a reversed spatial design
of reference-target pair to Experiment 1), the AI pattern showed no spatial influences
among three conditions. This result discrepancy could be accounted for by the processing
of the spatial position of the target stimulus, which was irrelevant for the task. Bearing in
mind that the reproduction task required to reproduce an estimated duration, the left-short
and right-long mapping metaphor could determine the performance which was more accu-
rate when left or right targets were presented according to a left-to-right time representa-
tion. The accuracy pattern of Experiment 3 (with opposite locations of reference-target
pair) mirrored that of Experiment 1, whereas, in Experiment 4 (with an identical locations
of reference-target pair), AIs for C-C conditions were lower than other L-L and R-R con-
ditions. Hence, for Experiments 3 and 4 the processing of target position in space did not
completely account for the AI pattern. More probably, the spatial condition created in
Experiment 3 induced an (illusionary) movement of temporal stimuli which could influ-
ence the reproduction performance (Vicario et al., 2008). Also, the movement account
could explain the AI pattern of Experiment 1, given that there was a movement from a
central position (yellow rectangle) to left or right space (light-blue rectangle). On the con-
trary, in Experiment 4, there was no movement between reference and target stimuli and,
thus, no effect of L-L and R-R conditions on reproduction performance was found.

Finally, we did not find any modulation of the STEARC effect according to the spatial
conditions created in each experiment. The results confirmed the assumption that percep-
tual and motor levels were independent of each other (Ouellet et al., 2010; Santiago
et al., 2007) and did not interact (or at least, the contribution of the perceptual component
was reduced or masked) as hypothesized by the “intermediate coding” account when both
levels were involved in the task (Kong & You, 2011). One possible explanation could be
found considering the difference between temporal estimation and reproduction tasks.
These two tasks are directly comparable as they share common encoding and storing of
temporal information, but they differ in how participants use time information to make
responses (Bueti & Walsh, 2010; Bueti et al., 2008). In the time estimation task, the
motor response is required in order to make an estimation (i.e., shorter-longer), while in
the time reproduction task, the motor response is required to reproduce an estimated dura-
tion, and thus action duration is coded as part of a motor program and can be processed
prior to motor execution (Vidal et al., 1991, 1992). This feature of temporal reproduction
fits with Lewis and Miall’s (2006) theory which states that tasks that require replication
of a duration via an action may be especially reliant on the motor system. Including dura-
tion as a dimension of the response may involve different encoding and memory pro-
cesses than those engaged for temporal estimation. Thus, it is possible to posit that the
perceptual aspects of temporal estimation task are underlined both when the duration of
the reference stimulus is estimated and when the time judgment is performed. In contrast,
the perceptual aspects tend to be masked (or reduced) during the temporal reproduction task given that the motor component is more emphasized, especially when the temporal reproduction is performed. Moreover, this suggestion could give more relevance to the evidence that the STEARC effect is linked to response selection stage. According to Walsh (2003), time, space, and numbers are computed by a common metric and they are connected by a common (visuomotor) code for action, which is coded as a part of a motor program and is processed prior to motor execution (Vidal et al., 1991, 1992).

To sum up, the present research demonstrated a STEARC effect in a temporal reproduction task. This effect was mainly derived from the spatial information provided by the response buttons, given that we asked participants to perform the task twice pressing either a right or left key. The STEARC effect reflects a spatial-temporal association suggesting a timeline in which short temporal durations are represented on the left side and long durations on the right side of a space in a left-to-right mapping. This finding added further evidence that the spatial-temporal association arises at the response-related stage probably involving the (right) parietal cortex. Further studies should be carried out to investigate the contribution of the perceptual and motor components in spatial-temporal association in different temporal tasks.

References


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<td>AUTHOR: Please provide the volume number, page range for reference Di Bono et al. (2012).</td>
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<td>AUTHOR: Figure 1 has been saved at a low resolution of 101 dpi. Please resupply at 600 dpi. Check required artwork specifications at <a href="http://authorservices.wiley.com/bauthor/illustration.asp">http://authorservices.wiley.com/bauthor/illustration.asp</a></td>
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Using e-Annotation tools for electronic proof correction

Required software to e-annotate PDFs: Adobe Acrobat Professional or Adobe Reader (version 8.0 or above). (Note that this document uses screenshots from Adobe Reader X). The latest version of Acrobat Reader can be downloaded for free at: [http://get.adobe.com/reader/](http://get.adobe.com/reader/)

Once you have Acrobat Reader open on your computer, click on the Comment tab at the right of the toolbar:

This will open up a panel down the right side of the document. The majority of tools you will use for annotating your proof will be in the Annotations section, pictured opposite. We’ve picked out some of these tools below:

1. **Replace (Ins) Tool** – for replacing text.

   ![Replace (Ins) Tool](image1)

   **How to use it**
   - Highlight a word or sentence.
   - Click on the Replace (Ins) icon in the Annotations section.
   - Type the replacement text into the blue box that appears.

2. **Strikethrough (Del) Tool** – for deleting text.

   ![Strikethrough (Del) Tool](image2)

   **How to use it**
   - Highlight a word or sentence.
   - Click on the Strikethrough (Del) icon in the Annotations section.

3. **Add note to text Tool** – for highlighting a section to be changed to bold or italic.

   ![Add note to text Tool](image3)

   **How to use it**
   - Highlight the relevant section of text.
   - Click on the Add note to text icon in the Annotations section.
   - Type the instruction on what should be changed regarding the text into the yellow box that appears.

4. **Add sticky note Tool** – for making notes at specific points in the text.

   ![Add sticky note Tool](image4)

   **How to use it**
   - Click on the Add sticky note icon in the Annotations section.
   - Click at the point in the proof where the comment should be inserted.
   - Type the comment into the yellow box that appears.
USING e-ANNOTATION TOOLS FOR ELECTRONIC PROOF CORRECTION

5. **Attach File Tool** – for inserting large amounts of text or replacement figures.

   Inserts an icon linking to the attached file in the appropriate pace in the text.

   **How to use it**
   - Click on the **Attach File** icon in the Annotations section.
   - Click on the proof to where you’d like the attached file to be linked.
   - Select the file to be attached from your computer or network.
   - Select the colour and type of icon that will appear in the proof. Click OK.

6. **Add stamp Tool** – for approving a proof if no corrections are required.

   Inserts a selected stamp onto an appropriate place in the proof.

   **How to use it**
   - Click on the **Add stamp** icon in the Annotations section.
   - Select the stamp you want to use. (The **Approved** stamp is usually available directly in the menu that appears).
   - Click on the proof where you’d like the stamp to appear. (Where a proof is to be approved as it is, this would normally be on the first page).

7. **Drawing Markups Tools** – for drawing shapes, lines and freeform annotations on proofs and commenting on these marks.

   Allows shapes, lines and freeform annotations to be drawn on proofs and for comment to be made on these marks.

   **How to use it**
   - Click on one of the shapes in the **Drawing Markups** section.
   - Click on the proof at the relevant point and draw the selected shape with the cursor.
   - To add a comment to the drawn shape, move the cursor over the shape until an arrowhead appears.
   - Double click on the shape and type any text in the red box that appears.

For further information on how to annotate proofs, click on the **Help** menu to reveal a list of further options: