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Face Age is Mapped Into Three-Dimensional Space

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Abstract

People can represent temporal stimuli (e.g., pictures depicting past and future events) as spatially connoted dimensions arranged along the three main axes (horizontal, sagittal, and vertical). For example, past and future events are generally represented, from the perspective of the individuals, as being placed behind and in front of them, respectively. Here, we report that such a 3D representation can also emerge for facial stimuli of different ages. In three experiments, participants classified a central target face, representing an individual at different age stages, as younger or older than the reference face of 40 years. Manual responses were provided with two keys placed along the horizontal axis (Experiment 1), the sagittal axis (Experiment 2), and the vertical axis (Experiment 3). The results indicated that the younger faces were represented on the left/back/top side of the space, whereas the older faces were represented on the right/forward/bottom side of the space. Furthermore, in all experiments, the latencies decreased with the absolute difference between the age of the target face and that of the reference face (i.e., a distance effect). Overall, this work suggests that the spatial representation of time includes social features of the human face.

Keywords: STEARC-effect; Time perception; Face age

1. Introduction

The idea that time can be spatially represented has been widely explored and debated, and converging evidence indicates that a variety of time-related stimuli can be mapped onto hypothetical mental time lines oriented along the three spatial axes (Bender & Beller, 2014;

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Bonato, Zorzi, & Umiltà, 2012). As for the horizontal axis, time would be represented from left to right (e.g., Vallesi, Binns, & Shallice, 2008; Weger & Pratt, 2008), a type of spatial representation that, in Western cultures, would be shaped by the writing/reading direction (e.g., Fuhrman & Boroditsky, 2010; Pitt & Casasanto, 2020; Tversky, Kugelmass, & Winter, 1991). Time would also be represented along the sagittal axis following a back-to-front spatial representation (e.g., Rinaldi, Locati, Parolin, Bernardi, & Girelli, 2016; Torralbo, Santiago, & Lupiáñez, 2006), a mental representation aligned with the typical walking direction, by which we leave past events and/or encountered places behind us as we head toward the future. Lastly, there is growing evidence showing that time can also be mapped along the vertical axis, but the evidence in this case is mixed. Indeed, depending on the type of stimuli and the experimental task, in previous studies either bottom-to-top (e.g., Beracci & Fabbri, 2022; Beracci, Rescott, Natale, & Fabbri, 2022; Casasanto & Bottini, 2014; Dalmaso, Schnapper, & Vicovaro, 2023a; Ding, Feng, He, Cheng, & Fan, 2020; Stocker, Hartmann, Martarelli, & Mast, 2016; Xiao, Zhao, & Chen, 2018) or top-to bottom (e.g., Casasanto & Bottini, 2014; Dalmaso et al., 2023a; Topić, Stojić, & Domijan, 2022; Xiao et al., 2018) representations have emerged. While the bottom-to-top representation is consistent with the "more is up" metaphor, which closely resembles everyday activities such as stacking objects on top of each other (Myachykov, Scheepers, Fischer, & Kessler, 2014), the top-to-bottom spatial representation is consistent with the reading/writing direction, which, in Western cultures, proceeds not only from left to right but also from top to bottom. All this suggests that the vertical spatial representation of time is less defined than both the horizontal and sagittal representations.

From a methodological perspective, the association between time and space has been extensively investigated by adopting behavioral tasks in which, for instance, the participant is required to quickly to categorize a central stimulus according to its temporal meaning (e.g., past or future, brief or long, before or after, etc.). Typically, responses are given by pressing keys aligned along the spatial dimension of interest. This creates two possible time-space mappings, such as responding to stimuli referring to past/brief/before concepts with a left-side key and to stimuli referring to future/long/after concepts with a right-side key, or vice versa. The spatial-temporal association of response codes (STEARC) effect (Vallesi et al., 2008) refers to an advantage for one of the two time-space mappings, which is considered to be evidence of a spatial representation of time-related stimuli. For example, when responses to stimuli referring to future/long/after concepts are faster with the left-side (vs. right-side) key and responses to stimuli referring to future/long/after concepts are faster with the right-side (vs. left-side) key, this can be interpreted as evidence of a left-to-right spatial representation of time.

The STEARC effect closely recalls what has been largely reported in numerical cognition, namely, that numbers are spatially represented along a hypothetical mental number line which would be oriented left-to-right, back-to-front, and bottom-to-top (the spatial-number association of response codes or "SNARC" effect; see, e.g., Aleotti, Di Girolamo, Massaccesi, & Priftis, 2020; Dehaene, Bossini, & Giraux, 1993). The link between magnitude and space goes beyond time and numbers and embraces several other dimensions, such as size (e.g., Prpic et al., 2020), weight (e.g., Dalmaso & Vicovaro, 2019), and luminance (e.g., Fumarola et al., 2014). This would suggest a common tendency to connote magnitudes within a spatial domain (Holmes & Lourenco, 2011; Walsh, 2003, 2015). Several models and theories have been proposed to explain the relationship between magnitudes and space. For the sake of brevity, three of them are briefly illustrated here. First, cross-cultural evidence suggests that the already mentioned role of reading/writing direction of the participant could actually be implied (e.g., Dehaene et al., 1993). For instance, Shaki, Fischer, and Petrusic (2009) showed that the association between numbers and space went from left-to-right in Canadians (who read/write left-to-right), while it was inverted in Palestinians (who read/write right-to-left) and was absent in Israelis (who can read/write along both directions). Second, a theory of magnitude, or ATOM (Walsh, 2003, 2015), postulates the existence of a common system for processing numbers, time, and space, which would find support at a neural level. According to ATOM, all magnitudes should be represented similarly (from left-to-right, from back-to-front, and from bottom-to-top). Third, Proctor and Cho (2006) proposed the polarity correspondence model: magnitudes and space are treated as polarized concepts (i.e., positive vs. negative), with small quantities and the left/back/bottom parts of the space conceptualized as negative, and large quantities and the right/front/up parts of the space conceptualized as positive. Magnitude-space association effects arise because of the possible overlap between the two dimensions (e.g., a small number responded to with a left key).

Returning to the spatial representation of time, the STEARC effect has so far been documented by conveying time-related information through a variety of stimuli that can be divided into two main categories: on the one hand, the physical time duration of visual or auditory stimuli (Beracci et al., 2022; Dalmaso et al., 2023a; Ishihara, Keller, Rossetti, & Prinz, 2008; Mariconda et al., 2022; Vallesi et al., 2008); on the other hand, abstract time-related concepts described by words referring to past versus future actions/events (e.g., yesterday vs. tomorrow; Santiago, Lupiáñez, Pérez, & Funes, 2007; Santiago & Lakens, 2015) or by pictures representing different historical ages (e.g., ancient vs. futuristic cities; Miles, Tan, Noble, Lumsden, & Macrae, 2011).

A largely neglected topic is the possibility of reporting a STEARC effect within a social dimension—for instance, by presenting participants with facial stimuli at different age points. Faces are likely the most informative social stimuli we are asked to perceive and elaborate daily, and face age is a particularly salient social variable. We are typically particularly adept at extracting age from a face for two main reasons. First, extrapolating the age of a face is of fundamental importance given that during social interactions we tend to shape our own behavior according to others' age (e.g., we probably behave differently when interacting with a child than with an elderly person). Second, face age is a social dimension that changes relatively slowly over the years, and this is typically reflected in a rather stable and clear mental representation of faces of different ages (e.g., the face of a child can be quickly discriminated from the face of an elderly person). For these reasons, face age should act as a particularly effective trigger to elicit a STEARC effect within a social domain. To our knowledge, this possibility has only recently been explored by Dalmaso and Vicovaro (2021), who focused on the possible spatial representation of face age along the horizontal axis. More specifically, different faces belonging to unknown individuals of different ages (from 20 to 80 years) were used as targets. The task consisted of using a left or right keypress to categorize each target face as younger or older than a reference face of 50 years, which was presented at the beginning of the experimental block. In line with a distance effect (Moyer & Landauer, 1967), the results showed that response latencies decreased with the absolute difference between the target face age and the reference face age, which can be taken as evidence that face age magnitude was effectively processed by participants. Surprisingly, however, no evidence of a STEARC effect emerged. According to Dalmaso and Vicovaro (2021), this could be attributed to the use of several distinct identities, which potentially induced an exemplar-based representation of faces (i.e., a representation based on the discrimination of different identities), rather than a genuine time-based representation (i.e., a representation based on a the identity-independent dimension of face age). Therefore, the use of different identities could have compromised, if not entirely nullified, the development of a clearly defined spatial representation of face age along the horizontal axis.

It is worth mentioning that evidence of a STEARC effect in response to social stimuli (e.g., pictures of a person at different ages) has been found in some other works (e.g., Boroditsky, Fuhrman, & McCormick, 2011; Kolesari & Carlson, 2018; Xiao et al., 2018), showing that "early" was associated with the left and top part of the space, and "late" with the right and bottom part of the space. However, those works also included nonsocial stimuli (e.g., a picture of a fruit before and after being bitten), and the specific performance associated with the social stimuli, therefore, remains unclear. In addition, in this kind of study, a vertical representation of time emerged in Mandarin speakers but not in English speakers. According to Boroditsky et al. (2011), this reflects the presence of specific linguistic metaphors in Mandarin, which are absent in English, linking early/late time concepts with the vertical axis. Nevertheless, it is worth mentioning that the possible role of language in shaping the spatial mapping of time-related concepts is a debated topic, as vertical STEARC effects have also been documented in other languages, such as German (e.g., Stocker et al., 2016), Croatian (e.g., Topić et al., 2022), and, more relevant to the present context, Italian (e.g., Beracci & Fabbri, 2022; Dalmaso et al., 2023a). In summary, the literature examining possible STEARC effects for face age is still limited; it is not conclusive and requires additional research. The current work represents an attempt to shed new light on this topic by exploring the possibility of observing a spatial mapping of face age into three-dimensional space.

We conceived three experiments in which a task similar to that developed by Dalmaso and Vicovaro (2021) was used. We asked participants to utilize two response keys placed along the horizontal (Experiment 1), sagittal (Experiment 2), and vertical (Experiment 3) axis to categorize a central target face stimulus as younger or older than a reference face stimulus presented before the experimental block in a learning phase. Throughout the three experiments, we used only a single identity depicting an avatar male face whose age was varied artificially. In so doing, we were able to present participants with a well-controlled set of stimuli belonging to the very same unknown individual. For Experiment 1, we had two straightforward hypotheses. First, we expected to observe faster responses when younger and older faces were responded to, respectively, with the left and right keys, compared to the opposite mapping (i.e., left-older/right-younger). This would confirm the existence of a horizontal STEARC effect consistent with a left-to-right representation of face age (see also, e.g., Boroditsky et al., 2011; Vallesi et al., 2008; Weger & Pratt, 2008). Second, in line with the distance effect (Moyer & Landauer, 1967), we expected to observe a linear decrease in response latencies as the absolute difference between the age of the target face and that of the reference face increased (see also Dalmaso & Vicovaro, 2021).

2. Experiment 1: Face age representation along the horizontal axis

Here, participants categorized a central target face as younger or older than a reference face. Responses were provided through two possible response keys placed along the horizontal axis (i.e., left vs. right).

2.1. Materials and methods

2.1.1. Participants

As we planned to analyze the data through linear mixed effects models, including both items and subjects as random effects, the sample size was defined following dedicated guidelines (Brysbaert & Stevens, 2018). These guidelines indicate collecting a minimum of 1600 trials per experimental condition (in designs with repeated measures) to achieve adequate statistical power. Given that we planned to collect 60 trials per condition for each subject, at least 27 subjects were required. Thirty young adults, recruited from the University of Padova and naïve to the objective of the study, were tested (mean age = 22.43 years; SD = 3.96; mode = 21; range = 20–36; six males). We stopped data collection at the end of a booking session. Written informed consent was obtained individually from all participants prior to testing. The study was approved by the Ethics Committee for Psychological Research at the University of Padova (protocol 3881). All the participants were Westerners, and their reading/writing direction went from left to right. Three participants declared themselves to be left-handed. Manual preference was further assessed using the Edinburgh Handedness Inventory (EHI) short form (Veale, 2014), which provides a score on a continuous scale from −100 to +100 (i.e., strong preference for the left or the right hand, respectively). Here, the mean EHI score was +65.83 (SD = 50.85; mode = +100; range = −87.5 to +100). According to the EHI, two participants were classified as left-handed, four as mixed-handed, and 24 as right-handed.

2.1.2. Stimuli, apparatus, and procedure

The stimuli were 11 facial stimuli (300 × 400 pixels) belonging to the same model (i.e., a male with neutral expression; see Fig. 1). These faces were generated using FaceGen Modeler software (https://facegen.com/; version 3.4.1), which allows the creation of well-controlled realistic faces. Faces were also adjusted for luminance and spatial frequency through the SHINE_color MATLAB toolbox (Dal Ben, 2021) to eliminate potential perceptual confounding among stimuli. The face belonged to a White individual (i.e., the same ethnic group as the participants) to exclude potential social confounding factors (see also, e.g., Dalmaso, Vicovaro, & Watanabe, 2023b). The facial stimuli represented the model at 11 different ages ranging from 15 to 65 years, with a 5-year interval between consecutive ages. The face depicting the model at an age of 40 years was used as the reference stimulus for the age categorization task. In this way, the remaining faces were either younger than the reference (i.e.,

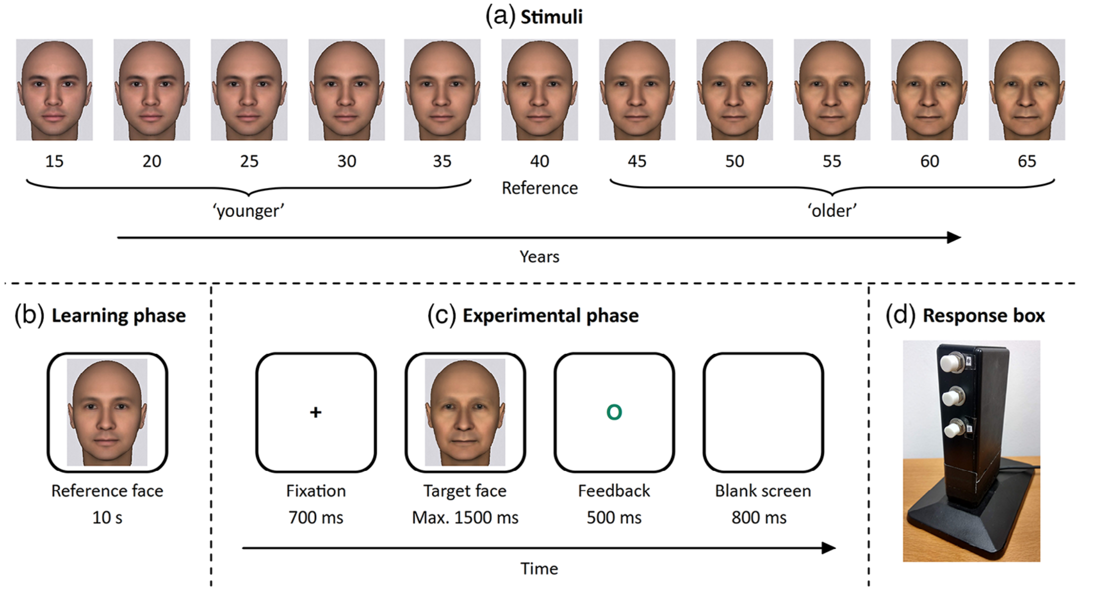

Fig. 1. The facial stimuli used in the experiment are depicted in panel A. The task consisted of a learning phase (panel B), during which participants were asked to look at the reference face for 10 s, and a comparison task, in which participants categorized the target fare as younger or older than the reference (panel C). The custom-made vertical response box used in Experiment 3 is also displayed (panel D).

15, 20, 25, 30, and 35 years) or older than the reference (i.e., 45, 50, 55, 60, and 65 years). The background color was set to white. The experiment was built using PsychoPy software (Peirce et al., 2019) and was delivered online through Pavlovia (Bridges, Pitiot, MacAskill, & Peirce, 2020).

At the beginning of the experiment, participants were required to pay attention to the reference face, which was presented in the center of the screen for 10 s along with the text "This person is 40 years old," placed above the face. Then, the experiment started. Each trial began with a black fixation cross (Arial font, letter height 0.085 norm) at the center of the screen, lasting 700 ms. Then, the target facial stimulus was presented. After a response was detected or 1500 ms had elapsed, central visual feedback appeared for 500 ms, followed by a blank screen lasting 800 ms. The feedback was a text (Arial font, letter height 0.065 norm) consisting of a green "O" for a correct response, a red "X" for a wrong response, and the words "Too slow" for a missed response. The task consisted of categorizing, as quickly and accurately as possible, the target face as younger or older than 40 years. Participants were asked to respond by pressing one of two horizontally aligned keys, namely, the "D" key with the left index finger and the "K" key with the right index finger.

There were two experimental blocks of 120 trials (i.e., 240 experimental trials in total), each preceded by a practice block of 10 trials (i.e., 20 practice trials in total). In both the experimental and practice blocks, each face was presented an equal number of times and in random order. The association between the response side (i.e., left vs. right) and the response category (i.e., younger vs. older than 40 years) was inverted in the two blocks. In the congruent block, participants responded to younger faces with the left key and to older faces with the right key, whereas in the incongruent block, the opposite was true. The order of the blocks was counterbalanced among the participants. After the main task, participants were required to complete a computerized version of the EHI (Veale, 2014).

2.2. *Results*

2.2.1. *STEARC effect*

Missed responses were rare (0.94% of trials); therefore, they were discarded and not analyzed further. Wrong responses (9.06% of trials) were discarded and analyzed separately. Correct responses with a latency smaller or greater than 3 SD from each participant's mean calculated for each condition were removed (1.48% of trials). The response times (RTs) of correct responses, and wrong responses, were analyzed with mixed-effects models using the lme4 R package (Bates, Mächler, Bolker, & Walker, 2015).

For RTs, we compared increasingly complex linear mixed-effects models through a likelihood ratio test, from the null model to the saturated one. The model that best fitted the data included, as fixed effects, response side (left vs. right), age category (younger vs. older), and their interaction; as random effect, it included the subject-specific random slope for the effect of age category. This model was then submitted to a Type I ANOVA (Satterthwaite's approximation for degrees of freedom) for linear mixed-effects models, through the lmerTest R package (Kuznetsova, Brockhoff, & Christensen, 2017). The main effect of age category was statistically significant, $F(1, 28.9) = 23.003$, $p < .001$, with shorter RTs for the older faces ($M = 590$ ms, $SE = 12.8$) than for younger ($M = 612$ ms, $SE = 12.6$); the main effect of response side was not significant, $F(1, 6326.1) = 0.053$, $p = .818$, as similar RTs emerged for left-side ($M = 602$ ms, $SE = 12.6$) and right-side ($M = 601$ ms, $SE = 12.6$) responses. Importantly, the interaction between age category and response side was significant, $F(1, 6326.3) = 13.011$, $p < .001$, indicating the presence of a STEARC effect. To investigate the interaction further, we performed planned Tukey's HSD (honestly significance difference) comparisons for linear mixed-effects models through the lsmeans R package (Lenth, 2016). For both the younger and older faces, a significant difference emerged between left-side and right-side responses. Participants responded more quickly to younger faces with the left key ($M = 607$ ms, $SE = 12.8$) than with the right key ($M = 618$ ms, $SE = 12.8$), $z = -2.368$, $p = .0179$, while for the older faces, the opposite was true, the right key RTs ($M = 584$ ms, $SE = 13.0$) being shorter than the left key RTs ($M = 596$ ms, $SE = 13.0$), $z = 2.731$, $p = .0063$ (see also Fig. 2, panel A).[1]

Wrong responses were analyzed by comparing increasingly complex mixed-effect logit models. The model that best fitted the data included, as fixed effects, response side (left vs. right), age category (younger vs. older), and their interaction. As random effect, it included the subject-specific random slope for the effect of age category. The main effect of age category was statistically significant, $b = 0.305$, $SE = 0.145$, $z = 2.105$, $p = .0353$, participants being more accurate for the younger faces ($M = 0.934$, $SE = 0.009$) compared to the older faces ($M = 0.906$, $SE = 0.009$),[2] while the main effect of response side was not significant, $b = -0.162$, $SE = 0.111$, $z = -1.452$, $p = .1466$, as similar accuracy emerged for left-side

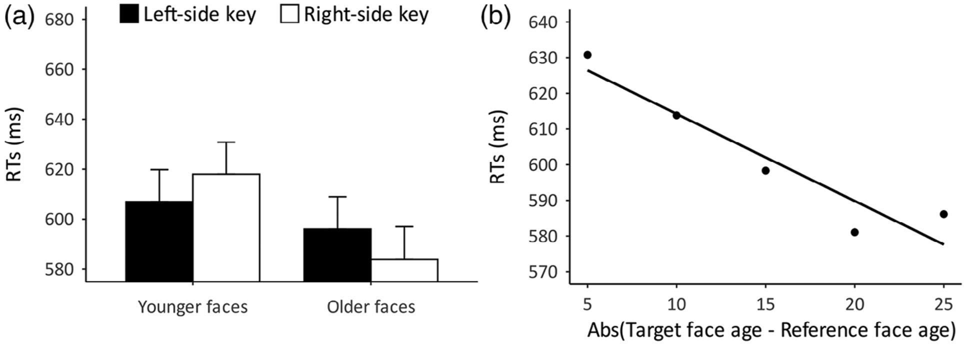

Fig. 2. Main results observed in Experiment 1. Panel A shows the mean RTs from the comparison task divided by each experimental factor (the error bars represent the standard error of the mean). Panel B represents the mean RTs as a function of the absolute difference between the age of the target face and the age of the reference face. The negative relationship reveals the presence of a distance effect.

(M = 0.924, SE = 0.009) and right-side (M = 0.919, SE = 0.01) responses. Of particular interest for the present study, the interaction between age category and response side was not significant, $b = 0.178$, $SE = 0.168$, $z = 1.057$, $p = .2903$.

2.2.2. Distance effect

RTs were analyzed through a linear mixed-effects model with the absolute difference between the age of the reference face and the age of each target face (i.e., 5, 10, 15, 20, and 25 years) as fixed effect, and the intercept for subjects as random effect. A significant negative relationship emerged between the absolute age difference and the RTs, $b = -2.400$, $SEb = 0.227$, $t(6353.195) = -10.57$, $p < .001$. This result indicates a distance effect, the RTs decreasing as the absolute age difference increases (see Fig. 2, panel B).

2.3. Discussion

The main results of Experiment 1 confirmed our two hypotheses. First, the statistically significant interaction between age category and response side confirmed the presence of a STEARC effect, with a left-to-right spatial representation of face age (see also, e.g., Boroditsky et al., 2011). Second, a distance effect emerged (Dalmaso & Vicovaro, 2021). Taken together, these results suggest that face age can be mapped onto space and that its spatial mapping arranges in a similar way compared to other time-related stimuli (Miles et al., 2011; Santiago & Lakens, 2015; Vallesi et al., 2008). In Experiment 2, we explored whether face age could also be mapped along the sagittal axis.

3. Experiment 2: Face age representation along the sagittal axis

As in Experiment 1, participants categorized a central target face as younger or older than a reference face. However, in this case, the responses were provided through two response keys placed along the sagittal axis (i.e., back vs. front). Consistent with previous studies on the representation of time along this axis (e.g., Rinaldi et al., 2016; Torralbo et al., 2006), we expected to observe a back-to-front spatial representation of face age. A distance effect was expected as well, in line with Experiment 1 and with previous studies (e.g., Dalmaso & Vicovaro, 2021).

3.1. Materials and methods

3.1.1. Participants

Because we intended to collect 60 trials per condition for each participant, at least 27 subjects were necessary (see Brysbaert & Stevens, 2018; see also Experiment 1). Hence, a new sample of 28 young adults, naïve as to the objective of the study, were enrolled at the University of Padova (mean age = 21.68 years; *SD* = 1.42; mode = 21; range = 20–27; eight males). We stopped data collection at the end of a booking session. Written informed consent was provided and obtained individually from all participants prior to testing. The study was approved by the Ethics Committee for Psychological Research at the University of Padova (protocol 3881). All the participants were Westerners, and their reading/writing direction went from left to right. One participant declared themselves to be left-handed. As in Experiment 1, manual preference was further assessed through the EHI. The mean EHI score was +73.66 (*SD* = 37.48; mode = +100; range = −100 to +100). According to the EHI, one participant was classified as left-handed, two participants as mixed-handed, and 25 participants as right-handed.

3.1.2. Stimuli, apparatus, and procedure

Everything was identical to Experiment 1, with the following exception: responses were provided along the sagittal axis—that is, participants were asked to respond, with their dominant hand,[3] by pressing the "B" key with the index finger and the "Y" key with the middle finger. Note that this response mapping has been used in previous work (e.g., Pratt, Kingstone, & Khoe, 1997; Voyer & Boles, 2007).

3.2. Results

3.2.1. STEARC effect

Data analyses were performed as in Experiment 1. Missed responses (0.4% of trials) and RTs 3 SD above or below each participant's mean calculated for each condition (1.39% of trials) were removed and not analyzed further. Wrong responses (7.5% of trials) were discarded and analyzed separately.

The model that best fitted the RTs data included, as fixed effects, response location (back vs. front), age category (younger vs. older), and their interaction; as random effect, it included the subject-specific random slope for the effect of response location. The main effect of age category was statistically significant, $F(1, 6048.8) = 34.567$, $p < .001$, with shorter RTs for the older faces ($M = 604$ ms, $SE = 14.8$) than for the younger faces ($M = 623$ ms, $SE = 14.8$). The main effect of response location was also significant, $F(1, 27.1) = 11.795$, $p = .002$, with shorter RTs for the "back" key ($M = 606$ ms, $SE = 14.0$) than the "front" key (M

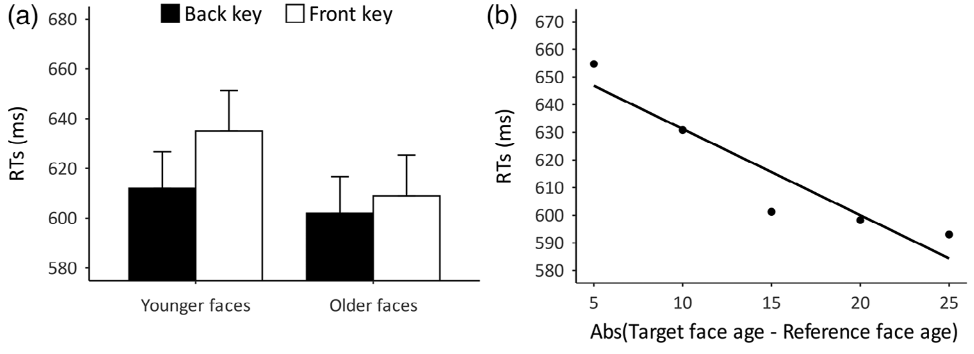

Fig. 3. Main results observed in Experiment 2. Panel A shows the mean RTs from the comparison task divided by each experimental factor (the error bars represent the standard error of the mean). Panel B represents the mean RTs as a function of the absolute difference between the age of the target face and the age of the reference face. The negative relationship reveals the presence of a distance effect.

= 621 ms, $SE = 15.6$). Importantly, the interaction between age category and response location was significant, $F(1, 6050.0) = 6.414$, $p = .011$, indicating the presence of a STEARC effect. Planned Tukey's HSD comparisons showed no significant differences between "back" ($M = 601$ ms, $SE = 14.2$) and "front" ($M = 608$ ms, $SE = 15.8$) responses for older faces, $z = -1.268$, $p = .205$, while for younger faces, participants responded significantly faster with the back key ($M = 611$ ms, $SE = 14.2$) than with the front key ($M = 634$ ms, $SE = 15.8$), $z = -4.266$, $p < .001$ (see also Fig. 3, panel A).[4]

For wrong responses, the model that best fitted the data included, as fixed effects, response location (back vs. front), age category (younger vs. older), and their interaction. As random effect, it included the subject-specific random slope for the effect of age category. The main effect of age category was statistically significant, $b = 0.665$, $SE = 0.167$, $z = 3.989$, $p < .001$, participants being more accurate for the younger category ($M = 0.952$ $SE = 0.005$) compared to the older ($M = 0.910$, $SE = 0.009$). The main effect of response location was also significant, $b = 0.254$, $SE = 0.118$, $z = 2.155$, $p = .0312$, participants being more accurate with the "front" key ($M = 0.942$, $SE = 0.006$) than the "back" key ($M = 0.926$, $SE = 0.007$).[5] More importantly for the present study, the interaction between age category and response location, $b = 0.024$, $SE = 0.195$, $z = 0.126$, $p = .8998$, was not significant.

3.2.2. *Distance effect*

As in Experiment 1, RTs were analyzed through a linear mixed-effects model with the absolute difference between the age of the reference face and the age of each target face as fixed effect and the intercept for subjects as random effect. A significant negative relationship emerged between the absolute age difference and the RTs, $b = -3.149$, $SEb = 0.228$, $t(6074.112) = -13.798$ $p < .001$. This result indicates a distance effect, with the RTs decreasing as the absolute age difference increases (see Fig. 3, panel B).

3.3. Discussion

The main results of Experiment 2 confirmed our two hypotheses and extended what was reported in Experiment 1. First, the statistically significant interaction between age category and response side confirmed the presence of a STEARC effect, with a back-to-front spatial representation of face age, in line with previous studies (see, e.g., Rinaldi et al., 2016; Torralbo et al., 2006). Even if the comparison between "back" and "front" responses was not significant for older faces, the presence of a STEARC effect was confirmed by the significant interaction between face age and response location. Such an unbalanced pattern of results is common in the literature on space-magnitude associations, especially when non-numerical magnitudes are considered (e.g., Chang & Cho, 2015; Dalmaso & Vicovaro, 2019; Dalmaso et al., 2023a; Giuliani et al., 2021; Ren, Nicholls, Ma, & Chen, 2011). However, the lack of specific studies aimed at revealing its possible causes invites additional research. Second, a distance effect emerged (see Dalmaso & Vicovaro, 2021). In Experiment 3, we evaluated whether face age could also be mapped along the vertical axis.

4. Experiment 3: Face age representation along the vertical axis

As in the previous two experiments, participants categorized a central target face as younger or older than a reference face. However, in this case, the responses were provided through two possible response keys placed along the vertical axis (i.e., bottom vs. top). As anticipated in Section 1, the introduction, the exploration of the possible vertical representation of time has produced mixed results, some results being consistent with a bottom-to-top representation (e.g., Beracci & Fabbri, 2022; Beracci et al., 2022; Casasanto & Bottini, 2014; Ding et al., 2020; Dalmaso et al., 2023a; Stocker et al., 2016; Xiao et al., 2018) and others consistent with a top-to-bottom representation (e.g., Casasanto & Bottini, 2014; Dalmaso et al., 2023a; Topić et al., 2022; Xiao et al., 2018). Considering this mixed evidence, here we evaluated experimentally which one of the two mental representations could emerge for face age.

According to the literature, the few studies that employed social stimuli to explore the vertical STEARC effect found evidence supporting a top-to-bottom representation in terms of an early-top/late-bottom association (see, e.g., Boroditsky et al., 2011; Kolesari & Carlson, 2018; Xiao et al., 2018). Even if this result was observed only in Mandarin speakers—who possess linguistic metaphors linking "early" to the upper part of space and "late" to the lower part of space—we thought it was premature to refuse the possibility of reporting a vertical representation of time in the current context, for two main reasons. First, in the aforementioned studies, faces were presented together with other nonsocial stimuli (e.g., a picture of a fruit before and after being bitten), for which the passage of time could be less evident (e.g., young and old faces probably elicit a stronger representation of the passage of time than the picture of a whole banana and the picture of the same banana with a bite mark). Therefore, even if linguistic characteristics may play a role in the emergence of STEARC effects, a "pure" presentation of faces of different ages could create a particularly relevant context that could trigger a top-to-bottom spatial representation in speakers of languages that lack metaphors linking time and vertical space. Second, two recent studies involving Italian participants (Beracci & Fabbri, 2022; Dalmaso et al., 2023a) found reliable evidence of a vertical STEARC effect. In particular, Dalmaso et al. (2023a) observed that when a relatively dense set of stimuli was used—which would favor the representation of time as a continuous dimension—a bottom-to-top representation of time emerged, in line with ATOM (Walsh, 2003, 2015), the polarity correspondence model (Proctor & Cho, 2006) and, more generally, the metaphor of "more is up." Because in the present study, a relatively dense set of stimuli was also used, a bottom-to-top representation could be expected. However, it is worth highlighting that in Beracci and Fabbri (2022), the stimuli were Italian time-related words, and in Dalmaso et al. (2023a), the stimuli were visual shapes that remained on the screen for variable durations. Therefore, no faces or social stimuli were used in these two previous studies, which makes them quite different from the present experiment and opens the possibility of different results.

Finally, in line with the previous two experiments and other studies (e.g., Dalmaso & Vicovaro, 2021), a distance effect was expected to emerge.

4.1. Materials and methods

4.1.1. Participants

As we planned to collect 60 trials per condition for each participant, at least 27 subjects were necessary (see Brysbaert & Stevens, 2018; see also Experiments 1 and 2). A new sample of 32 young adults was recruited from the University of Padova (mean age = 23.06 years; *SD* = 2.20; mode = 22; range = 20–32; seven males). We stopped data collection at the end of a booking session. All participants were naïve to the objective of the study. Written informed consent was provided, and obtained individually from all participants prior to testing. The study was approved by the Ethics Committee for Psychological Research at the University of Padova (protocol 3881). All the participants were Westerners, and their reading/writing direction went from left to right. Five participants declared themselves to be left-handed. The mean EHI score was +58.59 (*SD* = 62.98; *mode* = +87.5; range = −100 to +100). According to the EHI, four participants were actually classified as left-handed, two participants as mixed-handed, and 26 participants as right-handed.

4.1.2. Stimuli, apparatus, and procedure

Everything was identical to the previous two experiments, with the following two exceptions. The experiment was carried out in the laboratory and responses were provided along the vertical axis using a vertical response box (see Fig. 1, panel D). Two stickers with the symbols "#" and "*" were attached close to the response buttons. The instructions provided to the participants did not make any reference to the vertical spatial dimension, but instead informed them to respond with the "#" key and the "*" key. Participants were asked to respond by using their thumbs and the association between the response key and the hand was counterbalanced across participants (i.e., half of the participants used their right thumb to press the lower key and their left thumb to press the upper key, while the remaining half utilized

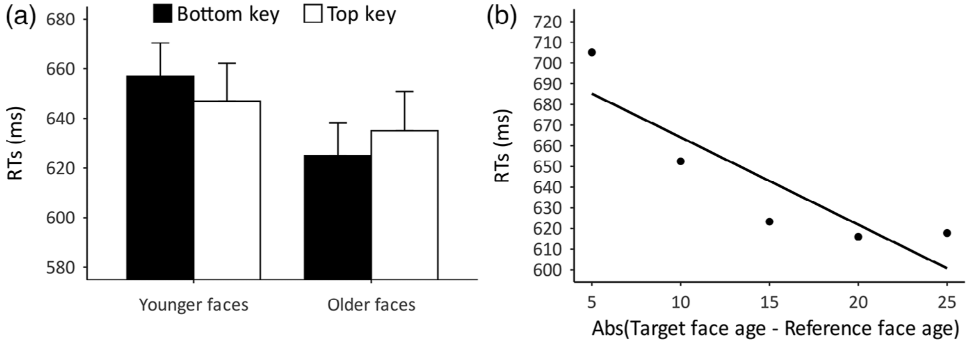

Fig. 4. Main results observed in Experiment 3. Panel A shows the mean RTs from the comparison task divided by each experimental factor (the error bars represent the standard error of the mean). Panel B represents the mean RTs as a function of the absolute difference between the age of the target face and the age of the reference face. The negative relationship reveals the presence of a distance effect.

the opposite key-thumb mapping). Please note that the same vertical response box was used in previous studies investigating the mental representation of magnitudes along the vertical axis (Bruzzi, Talamini, Priftis, & Grassi, 2017; Dalmaso et al., 2023a; Vicovaro & Dalmaso, 2021).

4.2. Results

4.2.1. STEARC effect

Data analyses were performed as in the two previous experiments. Missed responses (0.35% of trials) and outliers (1.63% of trials) were deleted and not analyzed further. Wrong responses (4.58% of trials) were discarded and analyzed separately.

The model that best fitted the RTs data included, as fixed effects, response location (bottom vs. top), age category (younger vs. older), and their interaction; as random effect, it included the subject-specific random slope for the effects of age category and response location. The main effect of age category was statistically significant, $F(1, 31.0) = 15.784$, $p < .001$, with shorter RTs for the older faces ($M = 630$ ms, $SE = 14.1$) than for the younger faces ($M = 652$ ms, $SE = 13.9$). The main effect of response location was nonsignificant, $F(1, 30.5) \approx 0.000$, $p = .998$, as similar RTs emerged for bottom-side ($M = 641$ ms, $SE = 12.9$) and top-side ($M = 641$ ms, $SE = 15.1$) responses. Importantly, the interaction between age category and response location was significant, $F(1, 7089.5) = 11.004$, $p = .001$, indicating the presence of a STEARC effect. Even if the planned Tukey's HSD comparisons showed no significant differences between "bottom" and "top" responses for either older, $z = -1.524$, $p = .127$, or younger faces, $z = 1.488$, $p = .137$, the means suggested that younger faces tended to be responded to faster with the top ($M = 647$ ms, $SE = 15.1$) than with the bottom key ($M = 657$ ms, $SE = 13.4$), whereas older faces tended to be responded to faster with the bottom ($M = 625$ ms, $SE = 13.1$) than with the top key ($M = 635$ ms, $SE = 15.8$; see also Fig. 4, panel A).[6]

For wrong responses, the model that best fitted the data included, as fixed effects, response location (bottom vs. top), age category (younger vs. older), and their interaction. As random effect, it included the subject-specific random slope for the effect of age category. The main effect of age category was statistically significant, $b = 0.459$, $SE = 0.213$, $z = 2.151$, $p = .0315$, participants being more accurate for the younger category ($M = 0.971$, $SE = 0.005$) compared to the older category ($M = 0.953$, $SE = 0.007$),[7] while the main effect of response location was not significant, $b = -0.139$, $SE = 0.140$, $z = -0.992$, $p = .3213$, as similar accuracy emerged for bottom-side ($M = 0.965$, $SE = 0.005$) and top-side ($M = 0.961$, $SE = 0.005$) responses. More importantly, the interaction between age category and response location was not significant, $b = 0.077$, $SE = 0.222$, $z = 0.347$, $p = .7288$.

4.2.2. Distance effect

As in previous experiments, RTs were analyzed through a linear mixed-effects model with the absolute difference between the age of the reference face and the age of each target face as fixed effect, and the intercept for subjects as random effect. A significant negative relationship emerged between the absolute age difference and the RTs, $b = -4.056$, $SEb = 0.216$, $t(7149.132) = -18.80$, $p < .001$. This result indicates a distance effect, the RTs decreasing as the absolute age difference increases (see Fig. 4, panel B).

4.3. Discussion

As in the previous two experiments, in Experiment 3, a statistically significant interaction between age category and response side emerged, confirming the presence of a STEARC effect. The results suggested the presence of a top-to-bottom spatial representation, thus aligning with a possible interpretation based on an early-top/late-bottom representation of face age along the vertical axis (see, e.g., Boroditsky et al., 2011; Xiao et al., 2018). Even if the significant interaction indicates the presence of a STEARC effect, none of the following comparisons between the “bottom” and “top” responses reached the canonical level of statistical significance. This could reflect the fact that the spatial representation of non-numerical magnitudes is less robust and stable than that of numbers (see, e.g., Giuliani et al., 2021), especially when the vertical dimension is considered (e.g., Dalmaso et al., 2023a; Stocker et al., 2016; Topić et al., 2022; Xiao et al., 2018). The distance effect was also significant, as in the previous two studies (see also Dalmaso & Vicovaro, 2021).

5. General discussion

In this work, we explored whether face age could trigger a STEARC effect along the horizontal, sagittal, and vertical spatial axes. In three experiments, participants were asked to classify a central target face as younger or older compared to a reference face aged 40 years. All facial stimuli belonged to the identity of the same individual. Manual responses were provided through response buttons placed along the horizontal (Experiment 1), sagittal (Experiment 2), and vertical (Experiment 3) axes. The results can be summarized as follows. Evidence of a three-dimensional STEARC effect emerged, attested by the interactions between response location and age category observed in all three experiments. These showed that face age was mapped from left to right, from back to front, and from top to bottom. In addition, in all three experiments, a distance effect emerged, as the latencies decreased with the absolute difference between the age of the target face and the age of the reference face. Taken together, these results are consistent with the idea that face age can be spatially mapped, as already reported for other temporal dimensions (e.g., Dalmaso et al., 2023a; Miles et al., 2011; Vallesi et al., 2008; Rinaldi et al., 2016).

As for the distance effect, its reliable presence in all three experiments indicates that face age was processed and mentally represented along a spatial continuum. These results replicate and extend what was reported by Dalmaso and Vicovaro (2021), showing that this pattern can be detected even when a single face is used. Turning to the STEARC effect, on the one hand, the spatial representations of face age emerging from Experiment 1 (i.e., from left to right) and Experiment 2 (i.e., from back to front) are consistent with a relatively established literature on the STEARC effect (see, e.g., Rinaldi et al., 2016; Vallesi et al., 2008). These results could reflect the influence of cultural habits, such as the writing/reading direction for the horizontal axis (Experiment 1), and the impact of certain attributes inherent in routine bodily movements, such as the walking direction for the sagittal axis (Experiment 2). The results of Experiments 1 and 2 are also consistent with both the ATOM (Walsh, 2003, 2015) and the polarity correspondence model (Proctor & Cho, 2006). On the other hand, the spatial representation of face age along the vertical axis followed a top-to-bottom direction. This result aligns with what emerged for Mandarin speakers in previous works in which participants were presented with pictures of both faces and nonsocial stimuli (Boroditsky et al., 2011; Kolesari & Carlson, 2018; Xiao et al., 2018). We believe that the high saliency and relevance of faces (and face age) for humans and their social interactions may have contributed to the emergence of spatial representation of face age in Italian speakers, too. However, future studies are necessary to explore the contribution of faces and nonsocial stimuli to the spatial representation of time along the vertical axis directly.

At the same time, the results of Experiment 3 are inconsistent with more recent works showing that a relatively dense set of time-related stimuli would tend to elicit a bottom-to-top time representation (e.g., Beracci & Fabbri, 2022; Dalmaso et al., 2023a, Experiment 2a) and, more generally, they contrast with the "more is up" metaphor (Myachykov et al., 2014) and the ATOM (Walsh, 2003, 2015). In this regard, it is worth mentioning that in Dalmaso et al. (2023a, Experiment 1a), a top-to-bottom spatial representation consistent with the reading/writing direction emerged for time-related stimuli that could be represented as belonging to two defined categories (e.g., long or short time intervals). Therefore, a possible reason why a top-to-bottom representation emerged in Experiment 3 is that, even though we used a relatively dense set of face ages, these were nonetheless represented in a categorical manner based on "earlier" and "later" temporal concepts (see also, e.g., Boroditsky et al., 2011; Kolesari & Carlson, 2018; Xiao et al., 2018). Indeed, the early/late distinction seems to reflect well how we generally categorize unknown people of different ages, placing them within categories (i.e., we generally label the age of an unknown person with adjectives such as "young," "middle aged," or "old," rather than providing a specific age in years). This interpretation is obviously speculative and further empirical evidence would be needed, also because the distance effect is consistent with the idea that face ages were represented along a continuum.

As regards the horizontal dimension, in Dalmaso et al. (2023a, Experiments 5–7), a pattern of results consistent with a left-to-right representation emerged irrespective of the density of the set of stimuli employed, which supports the idea that the representation of time (and quantities in general) is much more solid and less malleable along the horizontal than along the vertical dimension. Similar reasoning can be extended to the sagittal dimension, as we are not aware of any study that has found evidence against the back-to-front spatial representation of time. In sum, considering the solidity of the spatial representation of time-related stimuli along the horizontal and the sagittal dimensions, left-to-right and back-to-front spatial representations of face ages could be expected to emerge irrespective of the way face age was treated.

Lastly, it is worth noting that the results of Experiment 3 (as well as those of Experiments 1 and 2) are consistent with the polarity correspondence model (Proctor & Cho, 2006) if we assume that younger faces were positively connoted (and, therefore, associated with the top part of the space) and older faces were negatively connoted (and, therefore, associated with the bottom part of the space). Indeed, the literature on social cognition reported that younger people are generally perceived by others with more positive attitudes than older ones (see, e.g., North & Fiske, 2015). In any case, because we did not collect any measure of participants' attitudes toward younger and older faces, any interpretation based on polarity/valence should be taken with caution, and further research is needed.

The present work also extends what was reported by Dalmaso and Vicovaro (2021) and suggests that the use of a single face varying in age, although it reduces the generalizability of the results, appears to be a key factor for the emergence of STEARC effects. It is highly likely that the use of a single face may have helped participants to focus specifically on the age dimension rather than the identity dimension. In other words, the use of a single face may have made the age dimension particularly salient during the task. A limit related to our facial stimuli is their relatively low ecological validity with respect to pictures depicting real faces. We opted to use artificial stimuli, created with dedicated software, mainly for two practical reasons. First, every feature of artificial faces can be strictly controlled, thus increasing the internal validity. Second, we are not aware of any standardized face database containing faces of the same individual(s) at different ages. This is something other works could try to achieve to broaden the research perspectives concerning face processing.

It is important to note that in our three experiments, participants were required to directly classify the age of facial stimuli. A substantial body of literature has demonstrated that the link between space and magnitudes can also manifest in indirect tasks, especially when numbers are employed (e.g., participants classify a number as even or odd rather than as smaller or larger than a reference number; for a discussion on the distinctions between direct and indirect tasks, see, e.g., Mingolo et al., 2021; van Dijck, Gevers, & Fias, 2009; Wood, Willmes, Nuerk, & Fischer, 2008). With respect to non-numerical magnitudes, the effectiveness of indirect tasks remains somewhat ambiguous; for instance, and of particular interest for the present study, recent research has documented reliable STEARC effects in direct, but not indirect, tasks (Dalmaso et al., 2023a; Mariconda et al., 2022). Therefore, future investigations could explore the feasibility of eliciting a STEARC effect when facial age is treated as an implicit dimension. For example, male and female faces varying in age levels could be used and participants could be asked to differentiate between male and female faces rather than between younger and older faces.

Future studies could also incorporate a sample of older adults, to ascertain the generalizability of these findings across diverse age groups. Moreover, it would be valuable to also involve individuals from different cultures, as previous research indicates that they could produce different results. For instance, studies have indicated that Hebrew people often associate time with a right-to-left spatial representation (e.g., Ouellet, Santiago, Israeli, & Gabay, 2010), which suggests that a similar pattern might emerge when assessing face age.

Another facet of this study that warrants additional examination pertains to the presentation, at the beginning of the experiment, of the reference face in conjunction with numerical information (i.e., “This person is 40 years old”). We cannot entirely preclude the possibility that this numerical information might have prompted participants to engage in numerical processing rather than focusing solely on facial age as a distinct construct. Next, studies could address this concern by systematically contrasting the impact of numerical reference contexts (i.e., “This person is 40 years old”) with non-numerical ones (e.g., “This person is middle-aged”).

To conclude, the results provided by the current work suggest that face age can be represented along the three main spatial axes, which confirms and extends previous studies (Boroditsky et al., 2011; Dalmaso & Vicovaro, 2021), and extends the knowledge of STEARC effects within the social domain.

Notes

1 According to some studies (e.g., Brunyé, Gardony, Mahoney, & Taylor, 2012), there is a positive relationship between the degree of handedness and the tendency to represent concepts in the spatial domain. For this reason, participants' EHI scores were correlated with an overall index of the STEARC effect. The index was calculated as follows: M*i* = [RTi(younger, right) − RT*i*(younger, left)] + [RT*i*(older, left) − RT*i*(older, right)]; M*i* denotes the magnitude of the STEARC effect for the *i*th participant; RT*i*(younger/older, right) and RT*i*(younger/older, left) denote the mean latencies for the *i*th participant in response to younger or older faces by using the right-side and the left-side key, respectively; the stronger the link between younger-left and older-right, the greater the M*i* value (for a similar approach, see also Dalmaso & Vicovaro, 2019, 2021). A positive correlation would have indicated that as the degree of right-hand preference increased, so did the strength of the left-to-right spatial representation of face age. However, a nonsignificant negative correlation emerged, $b = -0.180$, $SEb = 0.217$, $t(28) = -0.829$, $p = .412$.

2 Given that RTs and wrong responses revealed signs of speed-accuracy trade-off concerning the effect of age category, the inverse efficiency scores (i.e., mean RT/1-proportion of wrong responses; see Townsend & Ashby, 1983) were computed. Two scores were computed for each participant, one for the younger faces and one for the older faces. The two

sets of scores were then analyzed with a linear mixed-effects model with age category as fixed effect and participant as random effect. A nonsignificant result emerged ($p = .232$).

3 Unlike Experiment 1, here responses were provided with one hand. This choice was made for practical purposes to provide participants with straightforward instructions. Importantly, a meta-analysis (Wood, Willmes, Nuerk, & Fischer, 2008) suggests that unimanual and bimanual response settings yield comparable effects in tasks assessing spatial-magnitude associations.

4 We computed the correlation between the degree of handedness and the magnitude of the STEARC effect in the same way adopted in Experiment 1, except that "left" and "right" were replaced with "back" and "front," respectively. A nonsignificant correlation emerged, $b = 0.426$, $SEb = 0.272$, $t(26) = 1.569$, $p = .129$.

5 Given that RTs and wrong responses revealed signs of speed-accuracy trade-off concerning the effects of age category and response location, the inverse efficiency scores for the two factors were computed and analyzed as in Experiment 1. In both cases, a nonsignificant result emerged ($ps > .177$).

6 We computed the correlation between the degree of handedness and the magnitude of the STEARC effect in the same way adopted in Experiment 1 (and 2), except that "left" and "right" were replaced with "bottom" and "top," respectively. A nonsignificant negative correlation emerged, $b = -0.013$, $SEb = 0.311$, $t(30) = -0.042$, $p = .967$.

7 Given that RTs and wrong responses revealed signs of speed-accuracy trade-off concerning the effect of age category, the inverse efficiency scores were computed and analyzed as in Experiments 1 and 2. Again, a nonsignificant result emerged ($p = .527$).

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Data availability statement

This study was not preregistered, and its data, materials, and codes are available on OSF: https://doi.org/10.17605/OSF.IO/GJU9X

Open Research Badges

This article has earned Open Data and Open Materials Research Design badges. Data and materials design are available at https://www.doi.org/10.17605/OSF.IO/GJU9X.

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