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Time drawings: Spatial representation of temporal concepts

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ABSTRACT

Time representation is a fundamental property of human cognition. Ample evidence shows that time (and numbers) are represented in space. However, how the conceptual mapping varies across individuals, scales, and temporal structures remains largely unknown. To investigate this issue, we conducted a large online study consisting in five experiments that addressed different time scales and topology: Zones of time, Seasons, Days of the week, Parts of the day and Timeline. Participants were asked to map different kinds of time events to a location in space and to determine their size and color. Results showed that time is organized in space in a hierarchical progression: some features appear to be universal (i.e. selection order), others are shaped by how time is organized in distinct cultures (i.e. location order) and, finally, some aspects vary depending on individual features such as age, gender, and chronotype (i.e. size and color).

1. Introduction

Time is an abstract entity that is not directly perceivable through our senses. Nevertheless, in everyday live, we use, represent, and measure time continuously. We talk about time, make gestures related with different time events or periods, and represent time in spatial coordinates in clocks and calendars. The use of spatial features to represent time extends beyond clocks and calendars: when we talk, gesture or draw about events, or durations, we make use of universal spatial cues (Casasanto & Boroditsky, 2008). Time is also represented according to cultural and contextual features (Nunez & Cooperrider, 2013). For example, while English or Spanish speakers typically represent the future as in front of them (and the past behind), Aymara people represent the future behind them (and the past to their front) (Boroditsky, 2000; Nunez & Cooperrider, 2013; Nunez & Sweetser, 2006). Spatial and cultural features are also used in conjunction. Some cultures refer to time in absolute spatial coordinates: for example, an Australian Aboriginal group (the Kuuk Thaayorre) conceptualize time as flowing from East to West (Boroditsky & Gaby, 2010; Gaby, 2012) and in the Tzeltal Maya (Mexico), time is conceptualized as flowing uphill (Brown, 2012), independently of their body orientation.

Cultures that use a written language can also refer to time using a horizontal axis. Writing direction and/or spatial and temporal metaphors (i.e., time as an arrow) used in everyday linguistic interactions shape how time is represented. For example, English and Spanish speakers write rightwards and associate the past with the left and the future with the right, while Hebrew and Arabic speakers write leftward and have the opposite spatial mapping, they associate the past with the right and the future with the left (Boroditsky, Fuhrman, & McCormick, 2011; Boroditsky & Gaby, 2010; Fuhrman & Boroditsky, 2010).

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In experimental tasks that require building associations between temporal and spatial referents, responses are faster when past or early events are associated with the left side of the space (and future or later events, with the right) (Bonato, Zorzi, & Umilta, 2012; Santiago, Roman, Ouellet, Rodriguez, & Perez-Azor, 2010). This effect, termed the Spatial Temporal Association of Response Codes (STARC), has been reliably observed across tasks (Ouellet, Santiago, Funes, & Lupianez, 2010; Ouellet, Santiago, Israeli, & Gabay, 2010; Santiago, Lupianez, Perez, & Funes, 2007). For instance, English speakers have been shown to associate early months and early days of a week with the left side of space (and later months and days with the right) (Gevers, Reynvoet, & Fias, 2003, 2004). The STARC effect suggests that time is mentally represented on a continuous spatial line with rightward orientation, where time flows from early to late or past to future (Bonato et al., 2012). Evidence suggests that this mental timeline is asymmetric: near past and near future events are represented symmetrically from the present, but this symmetry tends to disappear for distant events. Past events are more strongly affected by the STARC effect than future events (Ding, Feng, Cheng, Liu, & Fan, 2015). A similar effect has been observed for numbers (Dehaene, Bossini, & Giraux, 1993): where small numbers are associated with the left side and large numbers with the right side of space on left-to-right writing cultures.

Two main theories have been proposed to explain the relationship between temporal and spatial representations. The Theory of Magnitude (ATOM, (Bueti & Walsh, 2009; Walsh, 2003)) proposes a domain-general representation of magnitude with a common neural substrate that predicts “more A, more B” associations. Support for this theory comes mainly from studies in human and non-human primates that show that different magnitudes (space, time, numbers, size, brightness, etc.) are associated. An alternative proposal is the Conceptual Metaphor Theory (CMT, (Lakoff & Johnson, 1980, 1999), which centers on the notion that abstract domains (i.e., target domains, like time or numbers) are mapped onto more concrete domains (i.e., source domain, space). In Lakoff and Johnson’s proposal, the evidence for this mapping is found in metaphors used in everyday language (Lakoff & Johnson, 1980, 1999). Both theories can be thought of as complementary: ATOM is related to magnitudes and CMT to relationships (Winter, Marghetis, & Matlock, 2015). The innate and evolutionary recycling of space in order to represent time proposed by ATOM is consistent with time duration mappings (i.e. more time equals larger size); however, it does not account for differences in how events modulated by experience (culture, writing direction) come to be represented using spatial features, which is one of the main explanatory advantages of CMT. Irrespective of the theory, temporal concepts can be classified into three main categories: deictic time (D-time), sequence time (S-time), and duration (T-span). D-time is represented relative to a reference point (“now”, “I”, “here”) and could have an internal or external perspective, depending on the location of the deictic center (Nunez & Cooperrider, 2013). S-time represents the relationship between time events without a reference point. D-time and S-time imply an ordered sequences of events, while T-span refers solely to an absolute magnitude or duration (Nunez & Cooperrider, 2013).

A straightforward procedure to study how time is spatially conceptualized is to ask participants to draw different time events according to how they represent them. In the Circles Test, for instance, participants draw three circles representing past, present and future (Cottle, 1967). The conceptual representation of time for each zone of time is derived from an analysis of the degree of overlapping (“relatedness”) and relative size (“dominance”) of the circles (Cottle, 1967). This early seminal study offers a paradigm that can be used in combination with digital data collection tools to obtain large data sets, which can allow for a broad and rich understanding of how different aspects of time are represented in imagery, including space, color at different scales, and granularities. This was the main goal and methodological approach used in this study.

We carried out a large and comprehensive online study that explored how people organize time in space by asking them to establish the spatial location, relative size, and color of specific time events. Our central hypothesis was that time is represented from an internal point of view, reflecting not only cultural biases but participants’ own preferences (in contrast to a unique and culture-dependent time representation). As individual preferences change with age and gender, we postulated that time representations would depend on the demographic characteristics of our sample, such that older people would tend to represent the past larger than younger people.

The study was divided into five experiments. On the first four experiments, we set out to study how location, size, and color are used to represent temporal events using different time granularities: 1-Zones of time (past-present-future), 2-Seasons, 3-Days of the week, 4-Parts of the day. The final experiment (5-Timeline) was designed to evaluate how temporal events are pictured on a line, including possible distortions in the spatial representation of time depending on the kind of events represented (personal vs. historical time).

Considering the characteristics of our sample (Spanish speakers), we expected time would be represented in a chronological order from left to right (independently of temporal granularity) in a horizontal straight line without any slope. Additionally, we hypothesized that the relative size of events represented would index individual preferences: favored time events (e.g. Saturday) would have a larger representation than less favored events (e.g. Monday). We expected that color would be used in different ways depending on the demands of each experiment. In experiments (Seasons and Parts of the day) where the events they were asked to draw have a strong association with a color (e.g., brown for autumn), we predicted that participants would choose such color more frequently and consistently. On other experiments (Zones of time and Days of the week), we expected color would be a proxy for valence (i.e. it would measure the respective value of different time events). For instance, we hypothesized that favored days of the week such as Saturday or Friday would be encoded with colors to which participants assign high valence. For the timeline experiment, we hypothesized that personal time would be overrepresented compared with historical time. Finally, we expected the order of time events’ selection to follow a chronological order in all five experiments.

2. Methods

2.1. Participants

This study was performed online and was part of an initiative referred to as TEDxperiments, which aims to capitalize on TEDx events to construct knowledge on human communication.[1] Most of the participants (73% of the final sample, n = 1454) came from the TEDxRiodelaPlata community, a group of people actively engaged with the local Buenos Aires TEDx initiative. Data were collected between September 2014 and February 2015. Participants were young adults (M = 28 yr, SD = 9.5 yr) and 48% were female (Supplementary Fig. 1A).

2.2. Study

Participants completed the study through a website where they had to log their personal information (name, age, and gender) after providing informed consent for online studies (which excluded participants younger than 18 yr old) approved by an institutional Ethical Committee [Centro de Educación Médica e Investigaciones Clínicas "Norberto Quirno" (CEMIC), Unidad asociada del Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), protocol N^{o} 435].

The study was divided into five experiments, with a short questionnaire at the end. On each of the first four experiments, participants saw a white screen or canvas of 800 × 500 pixels (px) and were asked to map each time event to a geometric figure, which changed between experiments (circle, square, rectangle). The experiment ended when the participant assigned all time events (for instance a circle for past, present, and future or a rectangle for each day of the week). In Experiment 5, participants were asked to select the length and the rotation of a line and, after that, to assign a location on the line to nine specific events; this experiment ended when all events were assigned a location. In Experiments 1 to 4, the initial location of each figure and the list of events were randomly assigned, the default size of figures was fixed on each experiment, and their default color was black. In Experiment 5, the initial spatial location of each event was random and the list of events was shown in one of two possible fixed orders (see below). Although the shape of the figures was fixed, participants could change other attributes of an event multiple times (on Experiments 1 to 4, location, size, and color; Experiment 5, location) and could return to previous events to make changes throughout each experiment. Participants could choose among eight colors (i.e., black, yellow, brown, purple, gray, red, green and blue), which were presented as small filled squares above the canvas. Instructions and all materials were in Spanish. Data were recorded at the end of each experiment. Because the order of experiments was the same for all participants and not all of them completed the entire study, sample size decreased from Experiment 1 (n = 1454) to Experiment 5 (n = 995) (Supplementary Fig. 1B). At the end of the study, participants were invited to complete a standard questionnaire about circadian preferences (Morningness-Eveningness Questionnaire, MEQ) (Horne & Ostberg, 1976).

Experiment 1: "Zones of time" (past, present, future). The experiment was inspired by the Circles test originally proposed by Cottle (1967). For this experiment, the shape of figures was fixed as an empty circle, with a default size of 70 px. Figure overlapping was allowed. Participants could edit the circles to define their radius, color and location.

Experiment 2: Seasons (summer, autumn, winter, spring). The default shape was a non-filled rectangle of 100 px $*$ 100 px. Participants could modify the height and width, location, and color of the rectangles. Rectangles could be overlapped. Participants defined the rectangle spatial location (x and y coordinates of its center), height, width, and color.

Experiment 3: Days of the week (Monday, Tuesday, Wednesday, Thursday, Friday, Saturday, Sunday). The default shape was a filled rectangle of fixed width (50 px) and height (100 px), which could be modified. Overlapping between rectangles was not allowed. Participants defined the spatial location, height, and color of each rectangle. This experiment was inspired by the way some people "see" days of the week (Hammond, 2013).

Experiment 4: Parts of the day (morning, afternoon, night). An empty circle was presented on the screen and participants were asked to allocate or assign each 'part of the day' a filled section of the circle (similar to a pie chart). The default size of each portion was randomly assigned according to a uniform distribution between 30° and 80°. Overlapping was allowed (sections of figure overlapping were slightly transparent, thus showing a different color than that of each respective section). Each portion was defined by a spatial location (of the center, in degrees from 0° to 360°), a size (in degrees from 0° to 360°), and a color.

Experiment 5: Personal (self-referential) and historical (non self-referential) events. First, participants were asked to choose the length and rotation of a straight line (with no arrowheads). The default rotation was 0° (horizontal) and the length 200 px. After establishing length and rotation, participants were asked to locate each of the following nine time events on the line: *"Year 1900", "World war II", "The Beatles", "My Birth", "My Childhood", "My Youth", "Today", "My Old age", "Year 2100".* On this experiment, the order of the buttons representing time events was not random but either chronological (as presented above) or pseudo-random *("Today", "World war II", "My Youth", "My Birth", "Year 2100", "The Beatles", "Year 1900", "My Childhood", "My Old age").* The position of time events could be modified before pressing the "Accept" button. The line was characterized by length and rotation (0–180°). Each time event was defined by its relative location on the line with a number between 0 and 1, using as scale the distance between 1900 and 2100. Based on the number of pixels between 1900 and 2100, we computed the number of pixels by year (px/yr) for each participant. This value, and the location of "My Birth" and "Today", allowed us to compare the objective age (the age reported by each participant) with the subjective age (in yr, using the px/yr and the number of pixels between "My Birth" and

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[1] http://www.tedxriodelaplata.org/tedxperiments/tiempoyespacio.

“Today”).

For some time events, participants needed to estimate the corresponding number of years (My Childhood, My Youth and My Old Age). To calculate how many years were assigned from My Birth to each of these time events, we used the number of years by pixel used to represent the Birth-Today period. To study time distortions along the whole timeline, we divided the line in time periods determined by the actual time when events occurred. We obtained the number of years (using the previously described px/yr scale) assigned to each of the five time periods: 1900 to World War II (1900-WWII), WWII to The Beatles (WWII-Beat), The Beatles to My Birth (Beat-Birth), My Birth to Today (Birth-Today) and Today to 2100 (Today-2100). We removed from the analyses those participants with inconsistent data (such as “My Birth” after “My Childhood”) and the 1% of the extreme values of Age distribution.

2.3. *Implementation*

The study was both designed and hosted using the Meteor framework (Meteor, Development, & Group, 2015). We used KineticJS (Rowell, 2015) for the graphic interface, and CoffeeScript as the language (Ashkenas, 2015). Data were converted from JSON format to tables using Python 3.4 (Van Rossum & Drake, 2011). The valence questionnaire was constructed using Google forms. We used the Shapely Python package to calculate Cottle’s measurements[2].

2.4. *Statistical analysis*

For most of the analyses were used the statistical software R (RCoreTeam., 2014) and the RStudio IDE (RStudioTeam., 2015). To study the color used on each experiment we employed the G test of independence (exact version of χ^2 test for independence in contingency tables), which allowed us to assess the interaction between color usage and the different experiments (Agresti, 1996). To compare the magnitude of the association between color usage and experiments we obtained the Cramer V coefficient, which ranges between 0 and 1 and indicates the grade of disproportion in a joint distribution (0 indicates colors were equally used on different figures and 1 indicates that a color was used for only one figure). We also calculated the inertia of the correspondence analysis to obtain the amount of variance accounted for by each color (Greenacre, 2008).

For numerical variables as location and size, we used mixed linear models with lme4 package (Bates, Maechler, Bolker, & Walker, 2015). The participant ID was set as a random effect. For some analyses, we ran a Repeated Measures ANOVA with time events as within-subjects factor, gender as between-subjects factor, and age as covariate.

For circular variables we used the circular statistic package (Agostinelli & Lund, 2013). To study if a circular variable was uniform, we used the Rayleigh Test. Circular mean and confidence intervals were calculated using bootstrap techniques.

To determine the relationship between two numerical values we computed the log(x/y). Using this scale, a result equal to 3 indicates that x is e^3 times higher than y, and -3 indicated that y is e^3 times higher than x.

Both frequency of color data and the comparison with Cottle’s work (dominance and relatedness) were analyzed using sequential tables of ANOVA along with the χ^2 test for the saturated model of Poisson counts. All data were represented as Mean ± SEM.

2.5. *Color valences*

To measure the association between valence and color, we ran an independent study consisting of a short questionnaire where participants were asked to choose a valence between 0 and 10 for each color (where 0 was very negative and 10 was very positive, the same eight colors we used in the main experiment were tested). We used two different pseudorandom orders for the presentation of the colors, and found no differences between them. This questionnaire was completely anonymous and respondents ($n = 261$) were recruited thought social networks and email lists. Green, blue and purple were the most positive colors and gray, brown and black, the most negative (Supplementary Fig. 2).

2.6. *Dominance and relatedness*

We automated the computation of dominance and relatedness, which were the measurements defined and computed by hand by Thomas Cottle (Cottle, 1967). These quantities measure the relationship between Zones of time (Experiment 1). Dominance quantifies the relative size of each figure compared to others and it is defined for each time event (past, present and future) separately. Dominance analysis (Cottle, 1967) was reproduced automatically to obtain a score for each circle (Zone of time). Here we compared the fraction of “Total” or High dominance (when a circle was the largest) between Zones of time and between the original Cottle’s work and the current one.

Relatedness denotes the overlapping between circles and was calculated for the whole experiment, depending on the number of circles overlapping and the magnitude of their overlap. “Atomicity or absence of relatedness” (Low relatedness) was established when circles were completely separated (no overlapping or contour contact), “Continuity” or partial relatedness when at least two circles were touching each other or intersected (Medium relatedness), and “Integration” or total relatedness when all circles intersected with each other or if a circle was inside another one (High relatedness).

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[2] https://github.com/alepulver/my-thesis/blob/master/results-tables/aggregators/cottle.pyh.

3. Results

3.1. Experiment 1: Zones of time (past, present and future)

We first studied how people picture Zones of time (past, present, future) using circular shapes. Each participant selected Zones of time, one at a time in an order of their choice, and assigned a spatial location, a size and a color to it (Fig. 1A).

We found a significant effect of Zone of time for location in the horizontal axis (chronological order from left to right) ($F(2, 4362.6) = 2395.7$, $p < .001$, $r_m^2 = .52$, $r_c^2 = .52$) and a smaller, but significant, effect in the vertical axis (chronological order upwise) ($F(2, 2905.8) = 40.36$, $p < .001$, $r_m^2 = .017$, $r_c^2 = .059$) (Fig. 1B). Most participants (81%) located Zones of time in chronological order from left to right and 36% ordered them from down to up (vertical axis) (Supplementary Fig. 3A). Similarly, the order of selection was not uniform ($\chi^2(5, n = 1454) = 672.8$, $p < .001$, Cramer's V = .481): from the six possible combinations, a high proportion of participants (41%) selected figures in the chronological order. Additionally, we found a significant main effect of Zones of time for figure Size ($F(2, 2905.7) = 171.37$, $p < .001$, $r_m^2 = .062$, $r_c^2 = .22$): a post hoc Tukey test showed that the past was represented as the smallest event followed, in decreasing order, by the present and the future (Fig. 1C). We also analyzed relative sizes and the overlap between events. Our results reproduced the main findings of Cottle's original work; however, while both studies found a larger proportion of high dominance for the future, in our study we found a relatively higher number of participants representing the present with high dominance compared to the original study (Supplementary Fig. 4).

Finally, we found a significant association between Zones of time and colors (G Test, $G = 799.8$, $p < .001$, Cramer's V = .30). We found that the use of green increased from past to future, gray and brown were almost exclusively used for the past, and red was mainly used for the present (Fig. 1D). Color-associated valence significantly increased from past to future (Fig. 1E, non-parametric Friedman test of differences among repeated measures, $\chi^2(2, N = 1454) = 420.8$, $p < .001$, Kendall's W = .145). Gray, green, brown and red accounted for most of the variance in the inertia analysis (34%, 25%, 18% and 11%, respectively; total inertia = 0.18). Because black was the default color, we could not disambiguate if it was selected or just left unchanged. These results suggest that colors normally associated with positive valences (like green) were used for the future and those associated with negative valence (like gray), for the past.

Thus, from past to the future circles increased in size, were allocated to the right, and were colored with higher valence colors.

3.2. Experiment 2: Seasons

In the second experiment, we studied how Seasons are represented in space, using rectangles (Fig. 2A). Because of the writing direction of Spanish, we hypothesized that seasons would be located linearly and chronologically from left to right (without vertical differences in location) starting from summer, which is the first season of the year in the Southern hemisphere. However, an alternative hypothesis was that seasons would be located cyclically, because they are repeated year after year. Our results showed a small but significant main effect of Season in the location in both axes (horizontal axis, $F(3, 5339.7) = 49.42$, $p < .001$, $r_m^2 = .027$, $r_c^2 = 0.027$; vertical axis, $F(3, 4009.8) = 17.03$, $p < .001$, $r_m^2 = .008$, $r_c^2 = .13$). Seasons were not represented linearly from left to right, but in a circular and counter-clockwise chronological order: beginning at the top with summer (Fig. 2B and Supplementary Fig. 3B). Additionally, the order of selection was not uniform ($\chi^2(23, n = 1337) = 376.2$, $p < .001$, Cramer's V = .306): 20% of respondents chose Seasons in a chronological order, starting with summer (12%) or autumn (8%). Size (√area) was significantly modulated by Seasons ($F(3, 4007.9) = 77.59$, $p < .001$, $r_m^2 = .015$, $r_c^2 = .66$). A post hoc Tukey test showed that both spring and summer were represented as significantly larger than autumn or winter (Fig. 2C).

Finally, color selection was strongly associated with Seasons (G Test, $G = 6794$, $p < .001$ and Cramer's V = .69). Fig. 2D shows the histogram of colors for each Season, revealing that brown is almost exclusively used for autumn; blue (and gray), for winter; green, for spring; and yellow and red, for summer. Colors were strongly associated with Seasons: the inertia of the Correspondence analysis showed that almost all colors have impact on the total variance (28% brown, 20% green, 19% blue, 11% yellow, 9.4% red, 8.6% gray; total inertia = 1.44). Color-associated valences depended on the Seasons (non-parametric Friedman test of differences among repeated measures, $\chi^2(3, N = 1337) = 1208$, $p < .001$, Kendall's W = .301) (Fig. 2E).

In sum, seasons were chronologically ordered in a cyclic and counter-clockwise fashion. Both location and selection order results suggested that the phase is well-defined: a high proportion of participants selected seasons in order, starting with summer (which starts on December 21th on Argentina, and is considered the first Season of the year) or with autumn (which is the first Season starting in the new year). Size was bigger for the warmer Seasons. Color selection was strongly associated with those colors that characterized each Season: each Season was colored with one or two specific colors for more than 50% of the sample.

3.3. Experiment 3: Days of the week

In the third experiment, we tested the spatial representation of the Days of the week, using filled rectangles of fixed width (Fig. 3A). We also hypothesized the Days of the week to be chronologically ordered from left to right (from Monday to Sunday or from Sunday to Saturday, according to cultural traditions). Alternatively, and similarly to Seasons, the Days of the week could be ordered cyclically. We found a significant main effect of Day of the week on spatial location on both axes (horizontal axis, $F(6, 7049.2) = 802.44$, $p < .001$, $r_m^2 = .35$, $r_c^2 = .41$; vertical axis, $F(6, 7043.9) = 10.09$, $p < .001$, $r_m^2 = .003$, $r_c^2 = .65$). The days of the week were chronologically located from left to right and upwards, excepting Sunday (Fig. 3B and Supplementary Fig. 2C). The location of Sunday on the horizontal axis was bimodal: some subjects (20%) located it at the beginning of the week and others (57%)

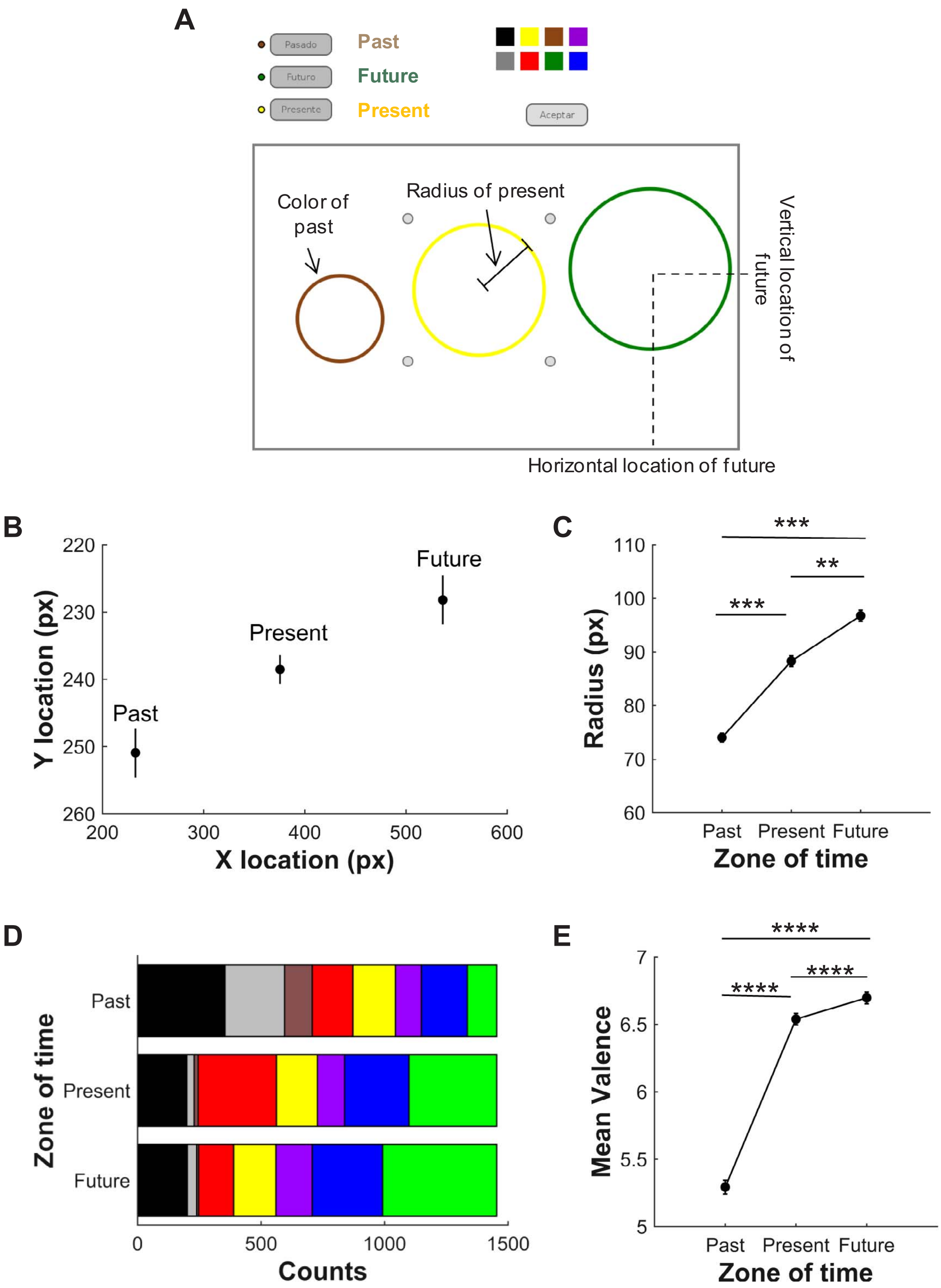

Fig. 1. Zones of time: past, present, future. (A) Example. Zones of time were pictured as empty circles that can overlap with each other. Participants determined the spatial location, the size and the color of each circle associated with an event (past, present and future). (B) Spatial location (of the center, in both axes) of Zones of time was significantly different along both axes: time flow was pictured from left to right and from bottom to top. (C) Size (radius) significantly increased from past to future. (D) Color choice depended on Zones of time: green increased from past to future. Gray and brown were almost exclusively used for past and a high proportion of participants used red to color the present. (E) Color-related valence increased from past to future. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

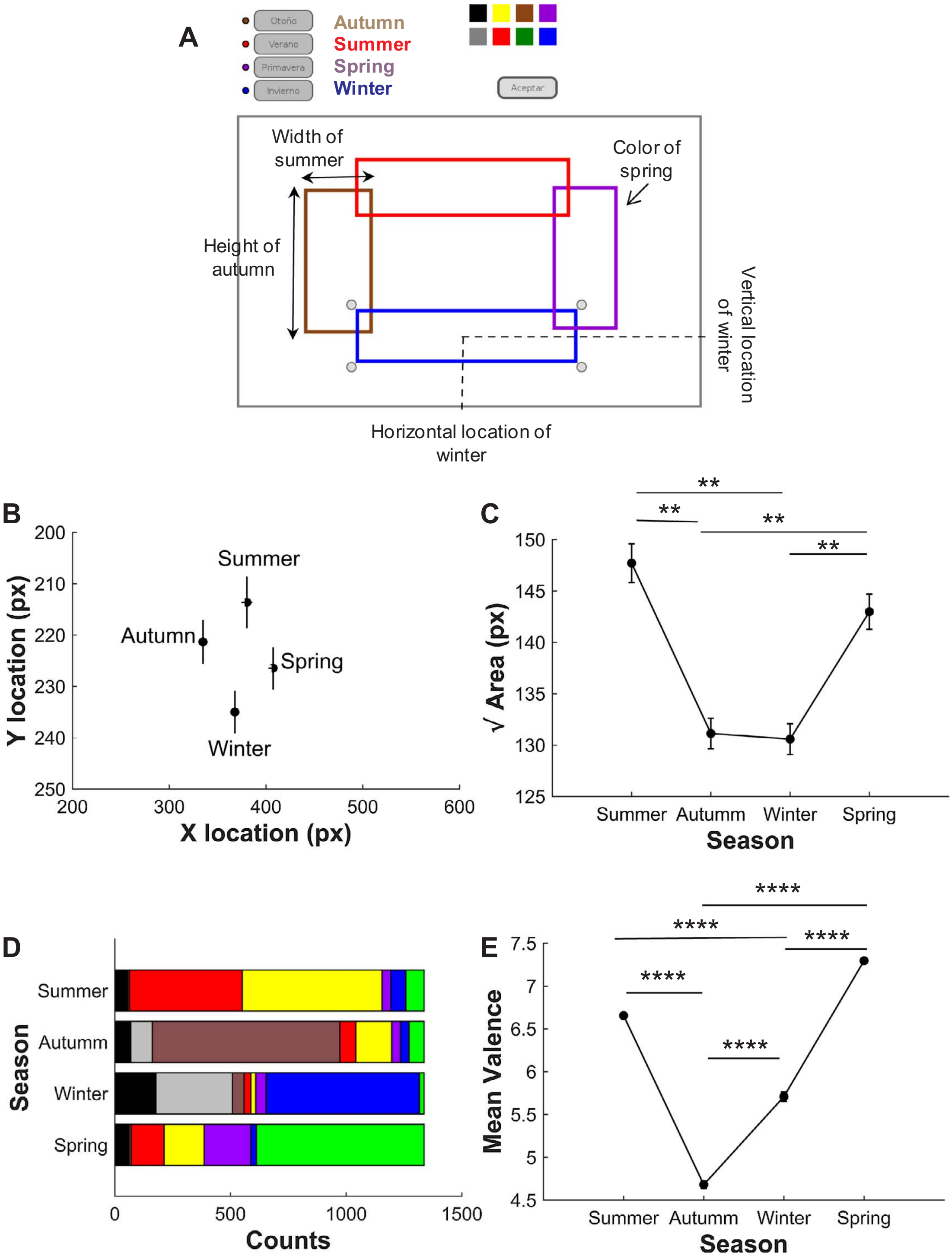

Fig. 2. Seasons. (A) Example. Season' shape was set as an empty rectangle, which can overlap with each other. Participants determined the location, the size and the color of each Season (summer, autumn, winter, spring). (B) Season location (of the center, in both axes), was significantly different in both axes, with Seasons ordered in a circular and counterclockwise fashion. All post hoc pair-wise comparisons were significant for both axes, excepting winter-summer in the horizontal axis, and autumn-spring and autumn-summer in the vertical axis (post hoc Tukey test). (C) Size (squared root of the area) of both summer and spring was significantly bigger than winter and autumn. (D) One or two colors mostly characterized each Season: summer was red/yellow for the 82% of participants, autumn was brown for the 61%, winter was blue/gray for the 74% and spring was green for the 54%. (E) Color-associated valences showed that autumn was associated with the lowest valence and spring with the highest one. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

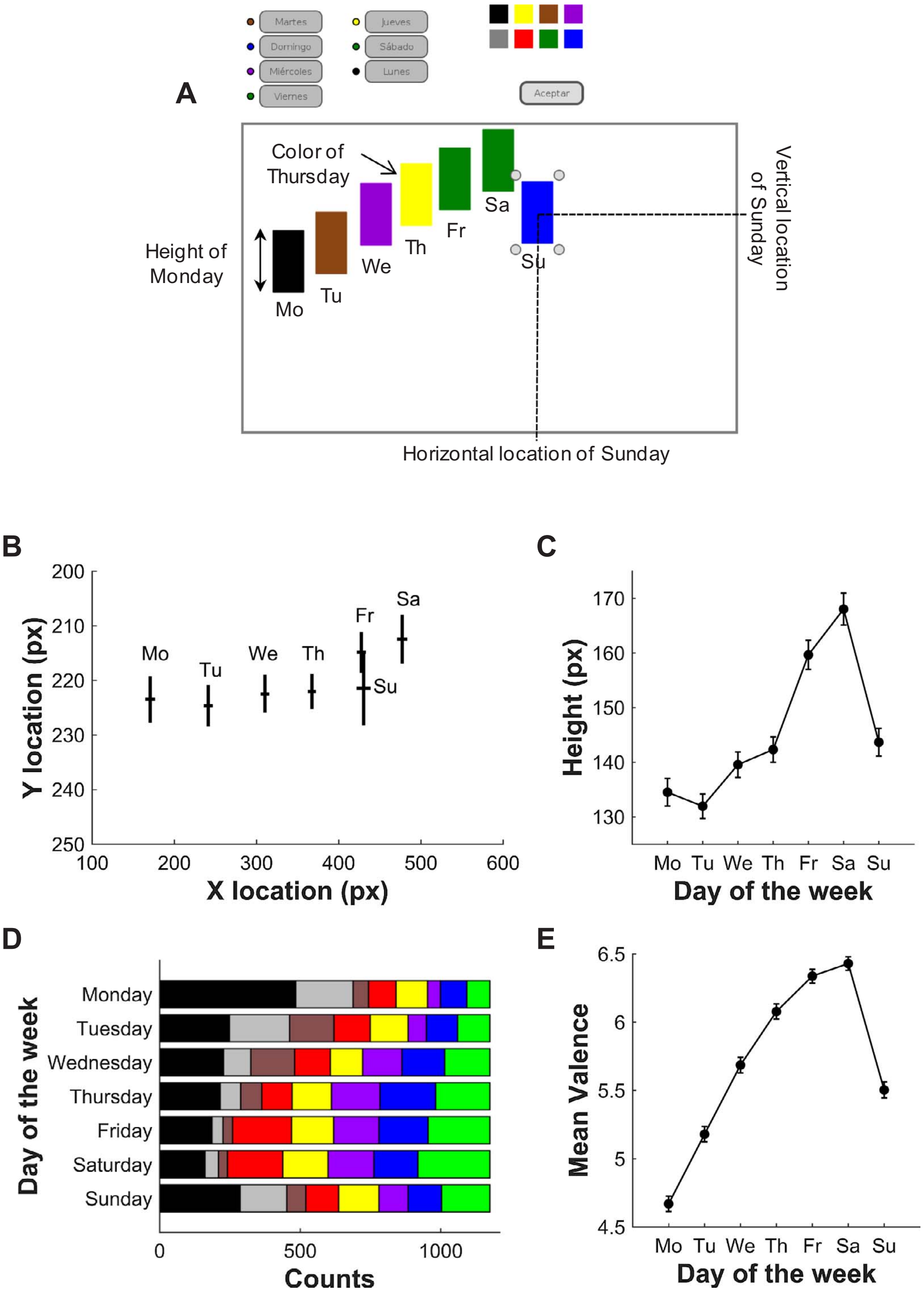

Fig. 3. Days of the week. (A) Example. Days of the week were pictured as filled rectangles. Overlapping between rectangles was not allowed in this experiment. Participants determined the location, the size and the color of each time event (Monday, Tuesday, Wednesday, Thursday, Friday, Saturday, Sunday). (B) The spatial location (the center in both axes) was significantly different for both axes, with Days of the week ordered from left to right, starting with Monday and from down to up. (C) Size (height) increased from the beginning of the week to the end of it (except for Sunday). (D) Color choice depended on the time event: green increased from Monday to Saturday, Gray decreased from Monday to Saturday. (E) Color-associated valence increased from Monday to Saturday. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

at the end. Additionally, participants did not select the time events randomly (χ^2(2, n = 1175) = 1005, $p < .0001$, Cramer's V = 0.654): 47% of the participants selected the Days of the week in order from Monday to Sunday. The Days of the week significantly differed in Size, which increased from Monday to Saturday (F(6, 7043.7) = 83.15, $p < .001$, $r_m^2 = .02$, $r_c^2 = .67$) (Fig. 3C). A post hoc Tukey test showed that both Friday and Saturday were represented significantly larger than the other Days of the week (and Saturday significantly larger than Friday). Color choice was slightly modulated for the Days of the week (Cramer's V = .15) with a significant association between colors and Days of the week (G Test, G = 1139, $p < .001$). Colors were differently distributed between Days of the week, with the use of black or gray decreasing from Monday to Saturday (Fig. 3D). The inertia of the correspondence analysis showed that colors were not as specific as we observed in the case of Seasons. Colors with higher relative impact on variance were gray, black, and brown (23.5%, 23%, 18%, respectively). Again, because black was the default color, participants could have just left it as it was. As we found for Zones of time, color usage for the Days of the week suggested that color valence was indexing preferences to specific time events. High-valence colors were used for days frequently referred as "better" (Friday, Saturday) and low-valence colors, for those considered "worst" (Monday, Tuesday). Color-associated valence was significantly modulated by Days of the week (non-parametric Friedman test of differences among repeated measures, χ^2(6, N = 1175) = 786.87, $p < .001$, Kendall's W = .112), with valences increasing from Monday to Saturday (Fig. 3E).

3.4. *Experiment 4: Parts of the day (Morning, Afternoon, Night)*

Parts of the day were pictured on an empty circle where participants allocated them as circle fractions (Fig. 4A). We found that a significantly higher proportion of participants (63%, Binomial Test $p < .001$) represented Parts of the day chronologically in a clockwise fashion (Fig. 4B and Supplementary Fig. 2D). Additionally, the order of selection of Parts of the day was not uniform (χ^2(5, N = 1111) = 1590, $p < .001$, Cramer's V = .846): a high percentage of participants (61%) selected Parts of the day in chronological order (morning, afternoon, night). Size significantly changed between Parts of the day (F (2, 3330.1) = 51.13, $p < .001$, $r_m^2 = .03$, $r_c^2 = .03$) (Fig. 4C). Post-hoc Tukey tests showed that both afternoon and night were represented significantly larger than morning.

Colors were unequally chosen between Parts of the day (Cramer V = .45, G Test, G = 1292, $p < .001$). Morning was represented predominantly with yellow, afternoon with green or red, and night with black or blue (Fig. 4D). The inertia of the correspondence analysis showed that yellow, black, green and red had higher impact in the total variance (37%, 35%, 14%, 9%, respectively; total inertia = 0.40). Color-associated valence changed between Parts of the day (non-parametric Friedman test of differences among repeated measures, χ^2(2, N = 1111) = 192, $p < .001$, Kendall's W = .086), with afternoon and morning having higher valence than night (Fig. 4E).

3.5. *Experiment 5: Timeline*

Here, we studied how temporal events in a scale of 200 years are mapped to a line. Our hypothesis was that the line would be located horizontally and events will be located chronologically. In addition, we hypothesized participants would overestimate personal events and underestimate historical events. Most participants extended the line (10% did not modify its length of, 200px) (M = 492.44px, SD = 152.80px). Line rotation distribution was not uniform (Rayleigh Test, z = .79, $p < .001$) and bimodal, with one peak at 0° (default orientation) and another at around 45° (M = 17.75°, SD = 37.36°).

To study time directionality, we evaluated the order in which events were located on the line. Some events were part of the participants' life (personal) and others were not (historical) (Fig. 5A). Most participants (91%) located events in a chronological order from left to right (Fig. 5B, Binomial test versus equal probability of right to left order, $p < .001$).

To evaluate the relationship between estimated and real number of years assigned to each event, we used the logarithm of the ratio between the number of estimated years and the number of real years to be estimated (log(estimated/real), which was 0 if both values are equal, positive if subjective years were higher than real years, or negative if the real number is higher that the estimated number of years. A RM ANOVA with a Greenhouse-Geisser correction determined that log(estimated/real) differed significantly between time intervals (F(3.76, 2742.5) = 157.43, $p < .001$, $\eta^2 = .18$). A post hoc Tukey test revealed that Personal time exhibited a significantly higher overestimation than other time intervals (excepting The Beatles to My Birth interval, which was not significant). Time distortion depended on the time interval with personal past (from "My Birth to Today") showing the highest overestimation [independently on the actual number of years estimated (Fig. 5C)].

3.6. *Interaction between location and size/color attributes*

Spatial location could function as an anchor for other properties of temporal events; indeed, both size and color valence could be determined by the X and/or Y location order of events. In order to test if the order in which time events were allocated modulated their size and color-associated valence, we evaluated the interaction between X- or Y-order of Zones of time (because there is an univocal chronological order: past, present, future) and size or color-associated valences.

Most, but not all, participants (81%) located Zones of time chronologically from left to right and 36% from bottom (down) to top (up). We grouped participants according to the X order of time events ("Rightward" versus "Others") and we tested the effect of this order on size and color-associated valence. Size was not affected by the X order (significant main effect of Zones of time: F(1.95, 2830.8) = 127.67, $p < .0001$, $\eta^2 = .081$, non significant main effect of X order: F(1, 1452) = 1.16, p = .28, $\eta^2 = .001$ and non significant interaction between them: F(1.95, 2830.8) = 2.37, p = .095, $\eta^2 = .002$). However, the X order modulated the effect of Zones of time on Valence: there was a main effect of Zones of time (F(1.85, 2680.31) = 205.85, $p < .0001$, $\eta^2 = .124$) and an

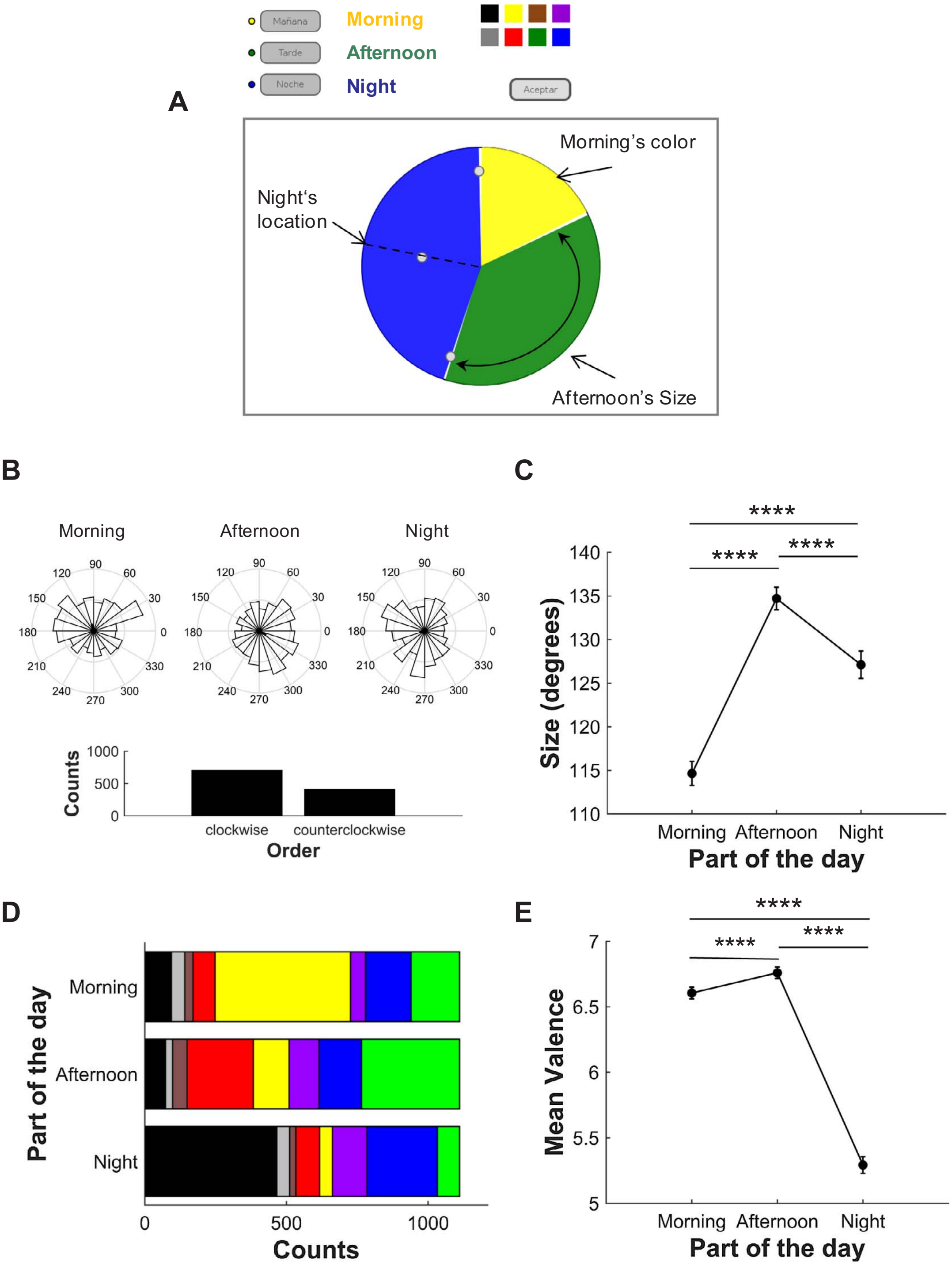

Fig. 4. Parts of the day. (A) Example. Parts of the day were represented as filled fractions of an empty circle. Participants determined the spatial location, size, and color of each Part of the day (morning, afternoon, night). Overlapping between time events was allowed. (B) Location (of the center of the fraction, in degrees) was multimodal for each part of the day. A significantly higher percentage of our sample (63%) represented Parts of day in a clockwise form. (C) Morning size was significantly smaller than both afternoon and night. (D) Color choice changed with Parts of the day, with each of them been characterized mostly by one or two colors: yellow for morning (43%), green/red for afternoon (52%) and black for night (42%). E) Color-associated valences were significantly different between Parts of the day: both morning and afternoon had higher valence than night. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

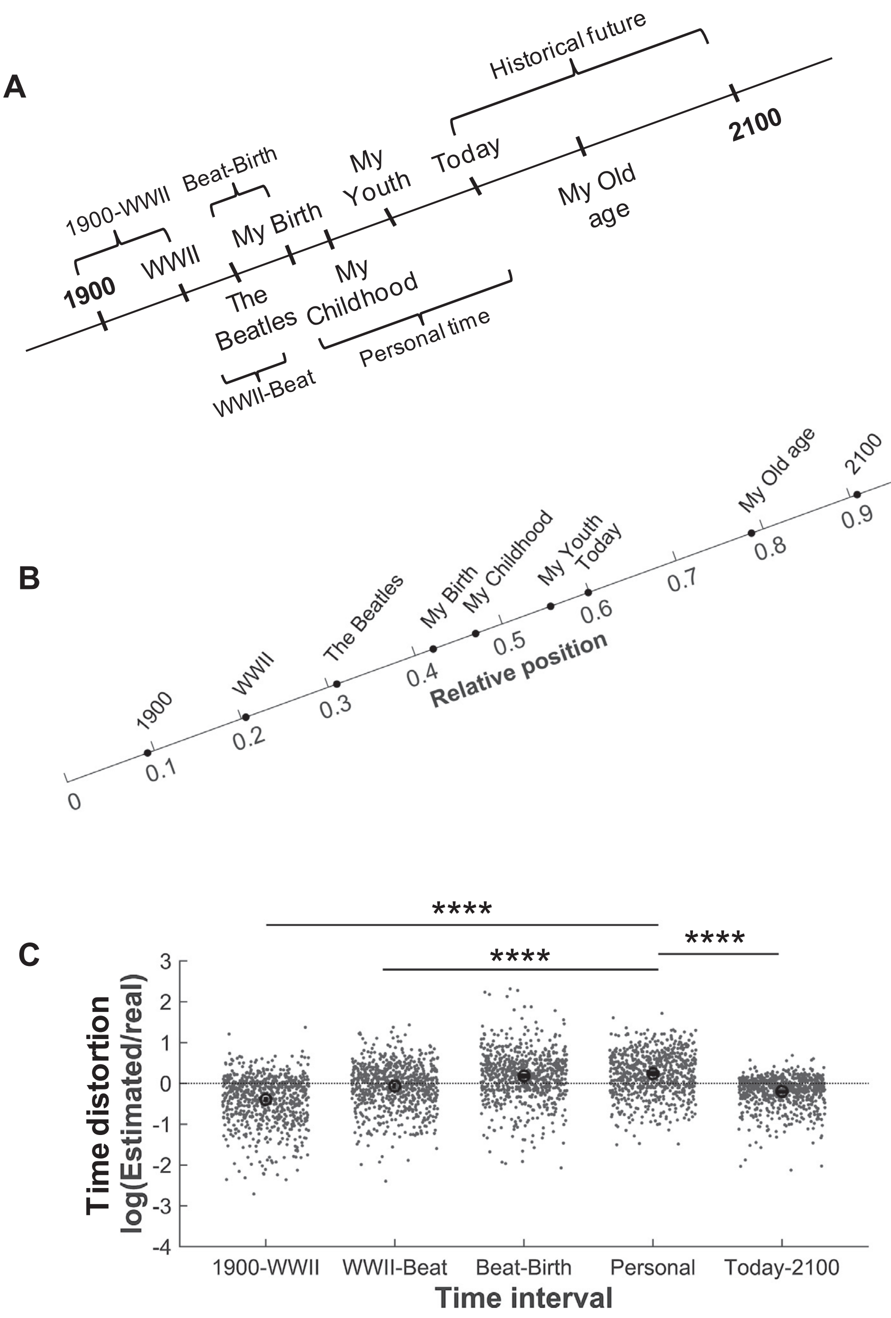

Fig. 5. Timeline. (A) Participants located the following time events on a line ('Today', '2nd World War', 'My Young', 'My birth', 'Year 2100', 'The Beatles', 'Year 1900', 'My Childhood', 'My Old age'). These events allowed us to divide the timeline in five segments. (B) Event location: time events were located in chronological ordering along the line, from left to right. (C) Time distortion changed with the time interval to be estimated. Participants overestimated their Personal time and underestimated almost all other events, independently on the number of years to estimate.

interaction with X location ($F(1.85, 2680.31) = 5.99$, $p < .003$, $\eta^2 = .004$), without a significant main effect ($F(1, 1452) = .53$, $p = .47$, $\eta^2 = .000$). Pairwise post hoc comparisons showed that Present was represented with significantly higher valence on the group with rightward orientation. When participants were categorized in two groups depending on the chronological order on the vertical axis ("Upward" versus "Other"), valences were not affected by Y order (main effect of Zones of time ($F(1.84, 2676.28) = 367.38$, $p < .0001$, $\eta^2 = .202$), main effect of Y order ($F(1, 1452) = .48$, $p = .49$, $\eta^2 = .000$) and interaction ($F(1.84, 2676.28) = .33$, $p = .70$, $\eta^2 = .000$)). However, Size was modulated by Y order: it was not only a main effect of Zones of time ($F(1.95, 2831.58) = 174.87$, $p < .0001$, $\eta^2 = .107$), but also an interaction with Y order ($F(1.95, 2831.58) = 7.37$, $p = .001$, $\eta^2 = .005$), without a main effect of Y order ($F(1, 1452) = .015$, $p = .90$, $\eta^2 = .000$).

Our results showed that the location order of time events on the horizontal axis modulated their valence: participants who ordered events from left to right, assigned higher valence to the Present. Moreover, participants who located Zones of time from bottom to top represented the future as the smallest.

3.7. Modulation of time representation by age, gender and chronotypes

In these analyses we tested whether human conceptualization of time is based on a subjective perspective of time, where attributes of time construals will be modulated by age, gender and/or daily preferences (or chronotypes). Because location of time events is highly affected by culture modulation (i.e. writing direction), we tested whether size and/or color-associated valences change with age, gender and/or chronotype.

Specifically, for Zones of time we tested three hypotheses. First, because younger individuals have a larger life expectancy than older participants, we expected the ratio between future and past to be higher for younger individuals. Second and consistently with previous results (Cottle, 1967), males should represent Zones of time with bigger sizes than females. Third, early chronotypes are future-oriented and late types are present-oriented (Nowack & van der Meer, 2013; Stolarski, Ledzinska, & Matthews, 2012) therefore we expected the ratio between future and present sizes and/or the color-associated valence to change with diurnal preferences. Our results showed that Age did not affect size (F(1, 1450) = 1.66, p = .20, η^2 = .001) nor modulated the effect of Zones of time (F(1.95, 2827.91) = 1.06, p = .35, η^2 = .001) and the ratio between future and past did not correlate with Age (r(1452) = −.004, p = 0.87). Consistently, age did not modulate the effect of Zones of time on color-associated valences (F(1.84, 2670.29) = .27, p = .76, η^2 = .000). We found a main effect of Gender on the Size of Zones of time: men used larger circles than women (F(1, 1450) = 10.55, p = .001, η^2 = .007). Additionally, men represented the future as significantly larger than women (F(1.95, 2827.91) = 3.52, p = .031, η^2 = .002, Supplementary Fig. 5A). The same result was obtained for Dominance, which was affected by the interaction between Zones of time and Gender. However, valence of Zones of time was not modulated by Gender (F(1.84, 2827.91) = 1.53, p = .22, η^2 = .001) (Supplementary Fig. 5C). Finally, we found no correlation between chronotypes (MEQ score) and future/present size (r(748) = .03, p = .48) nor an interaction of chronotypes (early and late tertiles) with Zones of time (F(1, 528) = .068, p = .79, η^2 = .000), on color-associated valences.

For Days of the week, we tested two specific hypotheses. First, cultural constraints suggest that younger participants should prefer Fridays and Saturdays more than older participants and, accordingly, both size and color associated valences of Friday and/or Saturday should decrease with age. Second, late chronotypes should dislike working days more than early chronotypes, since the former have higher social jetlag (Wittmann, Dinich, Merrow, & Roenneberg, 2006) and therefore we expected a direct correlation between working days' size and/or color-associated valences with MEQ score. We found no interaction between Age and Days of the week on Size (F(3.49, 4081.58) = 2.24, p = .072, η^2 = .002) nor correlation between Age and Friday' or Saturday' sizes. In addition, color-associated valence of Days of the week was not affected by Age

(F(4.92, 5764.8) = 1.94, p = .086, η^2 = .002). Regarding chronotypes, we found that color-associated valences of working days (mean of Monday to Friday), but not their Size, correlated with MEQ score (r(519) = .16, p < .001). Gender modulated the effect of Days of the week on valence (F(4.92, 5764.8) = 4.21, p = .001, η^2 = .004),but not on Size (F(3.49, 4081.58) = .83, p = .49, η^2 = .001) (Supplementary Fig. 5B and D).

For Parts of the day, we tested two hypotheses. First, because early types prefer morning rather than night, we expected the ratio between morning and night sizes should directly correlate with MEQ scores (higher for early types – high MEQ score-, and the opposite for late types). Second, because of cultural constrains and diurnal preferences, younger participants should prefer night instead of morning. In agreement with our first hypothesis, the ratio between morning and night sizes significantly correlated with MEQ score (r(573) = 0.21, p < .001). However, the ratio between morning and night sizes did not correlate with Age (r (1109) = 0.06, p = 0.07). Finally, for timeline we tested whether gender and age modulate time distortions (either personal or historical time), whether the overestimation of Personal time and/or the perceived Youth and Old age changed with participants' age. First, we found a main effect of gender (F(1, 727) = 4.14, p = .04, η^2 = .006) and an interaction with Time interval on time estimation (F(3.77, 2737.32) = 4.17, p = .003, η^2 = .006): women showed a larger underestimation of the historical past and a larger overestimation of Personal past and future than men (Supplementary Fig. 6). Age, as a covariate, modulated time estimation (F(1, 727) = 6.59, p = .01, η^2 = .009) and interacted with Time interval (F(3.77, 2737.32) = 12.57, p < .001, η^2 = .017).

Related with the second hypothesis, all participants overestimated their personal time by around 10 yr, independently of their age (b = 1.06, intercept = 10.92). Real age also explained a significant proportion of variance in estimated age, R^2 = .15, F(1, 802) = 145.56, p < .001 (Supplementary Fig. 7A).

The number of years estimated for youth increased with age (b = 0.31, intercept = 13.63), with Age explaining a significant proportion of variance in estimated youth, R^2 = .13, F(1, 802) = 119.47, p < .001 (Supplementary Fig. 7B). The same trend was observed for Old age: the number of years estimated increased with participants' age (b = 0.90, intercept = 44.01), with Age explaining a significant proportion of variance in estimated Old age, R^2 = .04, F(1, 802) = 36.31, p < .001 (Supplementary Fig. 7C). Our results suggested that for older participants both Old age and Youth corresponded to a higher number of years than for younger ones.

4. Discussion

In this study we investigated how people represent time in space. We used a direct approach namely to ask subjects to represent several temporal events at different granularities in a constrained drawing in which they had the liberty to choose parameters of geometric figures to express their mental image of time.

In terms of the different theoretical proposals that aim to explain the relationship between temporal and spatial representations, our results add mainly to the notions put forward by CMT: we studied the relationships between time construals (not their duration) at different granularities, where several conceptually related time events are pictured on space. Essentially, on each experiment we explored the spatial representation of different time events and the relationship between these representations, and evaluated both their temporal order and the individuals' perspective with respect to them. Even though we did not specifically ask about time durations, the general magnitude system proposed by ATOM could be expressed through "more time-higher/larger size" when size is assigned to each time event.

Objectively, the topology of both Zones of time and Timeline is linear. However, Seasons, Days of the week, and Parts of the day have cyclic structures. In our study, participants were free to represent the relationship between time events in whichever way they wanted (excepting both Timeline and Parts of the day, which were the last experiments to be presented and where participants were forced to locate time events linearly and cyclically, respectively). Consistently with their linear topology, participants located time events chronologically and linearly from left to right on both Zones of time and Timeline experiments. However, though both Seasons and Days of the week are cyclic, only Seasons were located on a circular fashion. Days of the week were located both chronological and linearly from left to right. This suggests that the mental representation of Days of the week does not represent its time topology. These results could be expressing the "zoom" of our time representation: when we think about Seasons, we acknowledge that there is a linear order (which is preserved on the circular representation we found) but participants saw it with a lower zoom than the "one-year-scale", so that the linear succession of Seasons is represented cyclically. However, even when Seasons were located cyclically, both the selection order and the location of different seasons reflected a well-defined phase. The linear location of Days of the week showed the opposite pattern suggesting that days are perceived with "a weekly zoom", with a start (mostly Monday or Sunday) and an end (Sunday or Saturday). An alternative interpretation is that Seasons are represented on a circle where each Season is equidistant to the following and to the previous one. Following a different mapping order, the perceived distance between two Days of the week is modulated by their identity: e.g. distance between Monday and Sunday is perceived as larger (a week) than between Tuesday and Wednesday (a day).[3]

Cyclic representations of numbers had been previously reported on cases of number-space synaesthesia (Hubbard, Ranzini, Piazza, & Dehaene, 2009; Piazza, Pinel, & Dehaene, 2006). Additionally, cyclical representation of months has been reported in non-synaesthetes (Seymour, 1980; Zorzi, Priftis, Meneghello, Marenzi, & Umilta, 2006). However, both small numbers and months could be organized as a clock, where each month (or number) corresponds to one of the 12 h and this could account for their cyclic representation.

The left-to-right time orientation we found was expected because of cultural influences (i.e. rightward direction of written Spanish) and it is consistent with previous results related to the STARC effect (Bonato et al., 2012; Santiago et al., 2007, 2010). However, time events were also chronologically ordered upwards on those experiments where time events were ordered linearly. If reading direction is responsible for the vertical orientation of time, the opposite direction should be found because of the secondary direction of Spanish (i.e., downwards). Nevertheless, the vertical effect of location is in line with the "more is up" metaphor: larger magnitudes are frequently associated with a higher vertical position (Holmes & Lourenco, 2012; Lakoff & Johnson, 1980). As for time, numbers are also spatially represented on a horizontal axis with the orientation associated with the writing direction (rightward on Western speakers, leftward on Eastern speakers) (Fuhrman & Boroditsky, 2010; Ouellet et al., 2010; Tversky, Kugelmass, & Winter, 1991). However, several studies also found a vertical association between numbers and space, with numbers increasing from bottom to top in most reports (Gobel, 2015; Hartmann, Gashaj, Stahnke, & Mast, 2014; Holmes & Lourenco, 2012). Additionally, the upward orientation could be representing the "happy is up" metaphor, where positive valences are mapped upward (Casasanto & Dijkstra, 2010; Lakoff & Johnson, 1999). To our knowledge this is the first evidence of a vertical STARC effect on a Western culture.

One of the main hypotheses of our study was that individual preferences would be expressed by the use of both size and color. Size results were consistent with our hypothesis: future was represented as the larger Zone of time, Summer and Spring were represented bigger than Winter and Autumn; Friday and Saturday, bigger than other Days of the week and both afternoon and night, bigger than morning. Larger stimuli are commonly associated with longer durations (Bueti & Walsh, 2009; Matthews, Stewart, & Wearden, 2011; Walsh, 2003; Xuan, Zhang, He, & Chen, 2007) and this could be translated as follows: time events perceived as longer are represented by bigger sizes. However, if size were used as a proxy for the objective temporal duration of events, the results would have been different (i.e. seasons would have had the same size, because they have the same number of days). In consequence, our results are in disagreement with ATOM and suggest instead that size is used to assign the relative significance of an event on each experiment as a proxy of individual preferences. However, one alternative interpretation that would be in line with ATOM is that individual preferences modulate the "relative duration" of time events: e.g. if participants prefer Saturdays, they could assign a higher relative duration for this day and thus represent it as larger than other less preferred days. In this last scenario, size could be indexing relative duration of time.

Specifically, participants represented Zones of time with size increasing from past to future. This is not consistent with an objective view of the time, neither personal nor historical—where both personal and historical Zones of time would have different lengths but the present should be the smaller. In addition, the ratio between past and future sizes did not increase with age. It is

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[3] This is captured by a joke where the same situation is repeated every day of the week. A child asked to his/her mother "ma', ma', what's for dinner?", the mother answer "pizza" and the child reaction depended on the Day of the week: on Monday the child comment "yeeeeeeeeeeeeeeeeeees!", on Tuesday "yeeeeeeeeeeeeeeees!", on Wednesday ""yeeeeeeeeeeeees!", on Thursday "yeeeeeeeeees!", on Friday "yeeees!", on Saturday "yes!", on Sunday "ok" and next Monday "yeeeeeeeeeeeeeeeeeees!" (Pescetti, 2008). The week started again on Monday.

possible that size is used to represent the more significant zone of time or the participant's time perspective (Zimbardo & Boyd, 1999). Temporal-focus theory proposes that different cultures gesture about past or future to their front or back depending on which Zone of time they are commonly focused on. For example, a comparative study indicated that while Spaniards are future-focused and represent the future in front of them, consistently with their linguistic metaphors, Moroccans gesture about the future as behind them, contrary to their own their linguistic metaphors (de la Fuente, Santiago, Roman, Dumitrache, & Casasanto, 2014). Consistently, size could be a proxy of temporal focus indexing Zone of time preferences: our population represented the future larger than both present and past, and indexed the future as being in front of them. However, our results showed a higher proportion of present-dominance compared with Cottle's, which could be showing a higher tendency "to live in the present", reflecting cultural changes across years. Moreover, chronotypes did not modulate Zones of time sizes, despite of early types being future-oriented and late types being present-oriented, according to their time perspective (Nowack & van der Meer, 2013; Stolarski et al., 2012). Instead, gender modulated size of Zones of time: in general, men represented zones of time in large circles and represented the future as significantly larger than women. Yet, it is hard to situate this finding within the literature as evidence about differences between genders in time perspective is not clear (Mello & Worrell, 2006; Zimbardo & Boyd, 1999). Chronotypes did modulate the size of Days of the week with late types representing working days smaller than early types. This result is consistent with what would be predicted depending on chronotypes' preferences: late types suffer more than early types the differences between social and internal times, the so-called social jetlag which results in a shorter sleep duration. Chronotype preferences were also evidenced in the size of Parts of the day, where each chronotype exhibited a larger representation of their preferred part of the day. Again, if participants in our study used size as a proxy for time duration as postulated by ATOM, results would not have been influenced by chronotypes.

Another hypothesis investigated in this study was that colors would indicate individual preferences on those experiments where colors are not directly associated with events (e.g. brown leaves in autumn). Both Seasons and Parts of the day were colored consistently with their natural color features: brown for autumn and green for spring, yellow for morning and black for night. Our results of Zones of time and Days of the week (which had no cultural- or nature-associated colors) suggest that time events were colored according to individual preferences: positive colors were associated with generally preferred time events (e.g., green Saturdays). It has been proposed that color perception evokes subjective emotions or feelings independently of cultural influences and with small gender-differences (Ou, Luo, Woodcock, & Wright, 2004). Our results showed that color-associated valences depended on gender, as previously shown for color preferences (Hurlbert & Ling, 2007). While gender modulation of Zones of time valences did not reach significance, Days of the week valences were modulated by gender, with women representing Tuesday, Wednesday and Thursday with higher valence than men. We interpreted these results as a consequence of small differences in color preferences between genders. Both men and women assigned similar valences to key days (Monday, Friday, Saturday and Sunday).

When we asked about "color valences" (positive-negative), we assumed that colors can be associated emotions, such a specific color could induce a distinct feeling in people (Cheng, 2002; Ou et al., 2004). We therefore propose that participants chose colors according to the emotions or feelings associated with each time event. Consequently, key days could be colored according to color-associated emotions and slight differences between genders are only observed on the other days.

We postulated that size and colors were used to index individual preferences for time events. This should be evidenced in an association between both attributes: size should be higher on those time events colored with higher valence colors. This is indeed what we found for both Zones of time and Days of the week, but not for Parts of the Day where the size of morning was low and the valence was high. However, as mentioned in previous paragraphs, Seasons and Parts of the day were colored with colors that refer to typical features of these time events.

Finally, in our final experiment we found that time events were correctly ordered on a line, although there were some temporal distortions: participants performed a "zoom in today" (personal time was overestimated while historical time was underestimated). Using different approaches, previous findings strongly supported the existence of a time representation on a mental line (with early/past events associated with the left side and late/future events with the right side of space) (Bonato et al., 2012; Di Bono et al., 2012; Gevers et al., 2003, 2004; Santiago et al., 2010) and the existence of time distortions on such mental timeline (Ding et al., 2015). As for numbers, previous findings support the distance effect on time events sequences (Bonato et al., 2012): responses are faster as temporal distance increase from the reference point (Santiago et al., 2010), self-related events are faster than non-self related events (Arzy, Molnar-Szakacs, & Blanke, 2008), and response time logarithmically decreases from the actual or imagined time location with the temporal distance to the life event to be classified as past or future events (Arzy, Adi-Japha, & Blanke, 2009). Moreover, past and future events are asymmetrically affected: the distance effect was stronger for past than for future events (Ding et al., 2015). In our study, we analyzed the spatial location of both personal- and historical-events on a line, finding differences related to the type of event. Independently of the number of years to be represented, participants overestimated their personal lifetime, compared with both the historical past and future. This result is consistent with our hypothesis that time is represented from a self-referential perspective. It is also in line with previous findings that showed that response time depended on the relative position where time events had to be classified as past or future: the distance effect was found to be relative to the imagined position of the subject (Arzy et al., 2009), reinforcing the idea of an egocentric perspective of life events (Arzy et al., 2008).

Personal time was overrepresented by about 10 years by all participants, independently on their age. However, the number of years corresponding to Youth or Old age did change with age: older participants represented both concepts later in their life than younger participants. Again, we think that participants represented time from their self-referential perspective: when older, they perceived Old age as farther and Youth as closer to their actual age. This is related with the time perspective or subjective sense of time left (Zimbardo & Boyd, 1999): old age is not fixed but relative to the subjects' own age. Consistently, age did not modulate the estimated size of the future. This suggests that if a person's temporal horizon does not depend on his/her age, the temporal duration of their perceived future might not change with age.

The modulation of time representation by personal preferences and self-referential perspective we found has implications for other areas of study. One of them could be handedness, though previous work has found that the STARC effect is not affected by it and that the effect was also maintained with crossed-hands (Vallesi, Binns, & Shallice, 2008). It would be interesting to explore in future studies how our results correlate with other individual characteristics, such as color blindness, visual imagery, or time perspective.

In this work we present strong evidence of the STARC effect on graphical representations of time events, with past or early events associated with the left side and future or late events, with the right side of space. Consistently with universal and cultural influences, events were selected in chronological order and located from left to right. Graphical representations were also consistent with their time topology, excepting Days of the week. Additionally, we described the use of other attributes (i.e. size and color) indexing the valence associated to each time event (or their characteristics if the association with color is direct, as for Seasons). Time representation changed with individual preferences: gender, age and chronotype modulated specific attributes of spatial construals of time, suggesting that time is represented from a self-perspective. Our results are consistent with CMT, which postulates that culture (mainly through language) and experience modulate the spatial representation of time. Individual preferences could interact with cultural effects through experience: preferences modulate behavior and, in turn, experience.

Finally, our results agree with a main effect of writing direction on spatial representation of time (i.e. location order), but also add new evidences of other attributes (size and color), which are used to express the valence of time events. When time concepts are graphically represented, culture and individual preferences interact to create our internal representation of time.

Acknowledments

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.concog.2018.01.005.

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