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ORIGINAL ARTICLE

In hindsight, life flows from left to right

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Abstract Three experiments investigated the mental representation of meaningful event sequences. Experiment 1 used extended (5 min long) naturalistic scenes excerpted from commercial movies. Experiments 2 and 3 presented everyday activities by means of sequences of six photographs. All experiments found both left–right and distance effects in an order decision task, suggesting that when contemplated in hindsight, experienced events unfold along a left-to-right analogical mental line. Present results are discussed in the context of the mental representation of other kinds of ordinal sequences, and other left–right effects reported in non-ordinal domains.

Introduction

As we experience the events of our life, we impose structure onto them, integrating events and subevents within a meaningful sequence (Zacks & Tversky, 2001; Zacks, Tversky & Iyer, 2001; Tversky, 2004). Later on, when contemplating the scene in hindsight, we recreate the structured sequence of events in front of our mind's eye. The goal of this investigation is to examine the form of this internal representation.

One possibility is that the sequence of events is re-enacted in a similar way to how it was perceived in the first place. This would be analogous to watching again the scene in our mind, as if re-playing a videoclip. It is a common subjective experience to live again past moments in this way. Another, and more intriguing, possibility would be to "unfold" the whole sequence in mental space from left to right, as if seeing a comic strip. This possibility appears, at first, less intuitive, because real life experiences are far more similar to videoclips than to comic strips. Moreover, it is unclear how the continuous character of a watched extended scene can be reconciled in the mind with the static nature of a left–right spatial representation.

The latter possibility gains indirect support from some recent reports regarding the mental representation of ordered sequences. Numbers are one key member of this category, and since the original report by Dehaene, Bossini & Giraux (1993), a sizeable literature has shown that numbers seem to lie along an analogical mental line extending from left to right, with smaller numbers falling on the left and greater numbers falling on the right (see Fias & Fisher, 2005, for a review). The main behavioral index of such representation consists of an interaction between response side and number position in the sequence (the Space-Number Association of Response Codes, or SNARC effect, as termed by Dehaene et al., 1993). The SNARC effect occurs both in tasks requiring explicit order comparisons (i.e., judging whether a number is greater or smaller than 5) and tasks for which order is irrelevant (i.e., categorizing a number as odd–even; Dehaene et al., 1993). Numbers also show semantic distance effects: comparing closer numbers is more difficult than distant numbers (Moyer & Landauer, 1967). The distance and SNARC effects together suggest a left–right analogical mental number line (see Dehaene, 1992, for a review and discussion). More compelling are the studies that show that even the simple act of seeing a digit is able to direct spatial attention to the left or right sides of the screen (Fischer, Castell, Dodd, & Pratt 2003; Cappelletti, Michielin, Zorzi, & Umiltà, 2007; see also Stoianov, Kramer, Umiltá, & Zorzi, 2008). Therefore, the

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resource to a spatial left–right arrangement looks quite mandatory in number processing and is not exclusively linked to a response representation.

Similar left–right and distance effects have been shown for other ordinal sequences, such as the months of the year, the letters of the alphabet (Gevers, Reynvoet, & Fias, 2003) and the days of the week (Gevers, Reynvoet, & Fias, 2004). Such sequences are also arbitrary and over-learned, but they lack the combinatoriality of number sequences. However, the question of how these ordinal sequences are represented is far from settled, with some reported replication failures of the left–right effects for months (Price & Mentzoni, 2008) and alphabet letters (Dehaene et al., 1993).

Some studies support the idea that both the representation of event sequences and time itself resource to a similar left–right spatialization strategy. Tversky, Kugelmass, & Winter (1991) asked children to place three stickers on a piece of paper to represent everyday event series such as breakfast, lunch and dinner. The majority of American children placed the stickers from left to right along a horizontal line. Prior work in our lab (Santiago, Lupiáñez, Pérez, & Funes, 2007; Torralbo, Santiago & Lupiáñez, 2006) using tasks where participants judge the past or future reference of temporal words (time adverbials and inflected verbs) found that words referring to the past were processed faster when presented on the left side of the screen and responded to with the left hand, and the opposite occurred for words referring to the future. Screen location and response side effects were additive. Finally, Vallesi, Binns & Shallice (2008) found a left–right congruency effect when participants classified a time interval as either short or long: responses to short intervals were faster with the left than the right hand, and the converse was true for long intervals.

Weger & Pratt (2008) went one step further to show that processing a past or future temporal adverb is able to bias the detection of a subsequent visual target presented to the left or right of the word. Current work in our lab (Ouellet, Santiago, Funes & Lupiáñez, 2008) replicates this finding and shows that it is possible to find independent additive effects due to the target's screen location and response side. The former strongly suggests a central origin.

A final line of evidence has to do with the gestures people perform while they speak. Núñez & Sweetser (2006) showed that Aymara and Spanish speakers tended to gesture from left to right when describing events unfolding in time. Though compelling, this evidence stays at the observational level and needs support from more controlled experimental studies.

The goal of the present investigation is to assess whether the left–right spatialization strategy is used in an as yet untested type of ordered sequences: meaningful event sequences. If we are correct that abstract time passing is conceptualized as flowing from left to right, meaningful event sequences as those we watch and experience as part of our everyday activities should also extend along a mental left-to-right line. However, meaningful event sequences differ in important ways from the types of sequences investigated so far: they are not arbitrary, but tied together by their internal causal and goal structure; and they are not over-learned, but understood and learned on the spot with little or no repetition, by virtue of the apprehension of that structure. It is also less clear why a left–right spatialization strategy would be useful for making order decisions in event sequences, as their internal structure is in principle enough to correctly perform the task. Finally, sequences such as numbers, months, week days and the alphabet are usually experienced literally from left to right in writing (both in running text as well as in charts, calendars and so on), which may favor the use of an analogous mental spatialization. In contrast, everyday events are witnessed, and therefore experienced in a completely different format. Because of these differences, the mental representation of event sequences is far from being a trivial question. If they happen to be represented in a similar way to the previously studied sequence types, it will add to the evidence for a general strategy of thought (see Walsh, 2003, for related arguments).

In order to test this hypothesis, Experiment 1 used naturalistic extended scenes: 5 min long video clips taken from commercial movies previously unknown to our participants. After watching each clip, participants carried out an order comparison task in which a reference frame (the central frame of the clip) was followed by another, comparison frame. Their task was to decide whether the comparison frame came before or after the reference frame in the clip by pressing a left or right key. We expected to observe both left–right and distance effects. In order to increase our control of variables, Experiment 2 turned to naturalistic event sequences presented by means of photographs. Left–right and distance effects were evaluated for the central events of sequences when the reference point is located before or after them. Finally, Experiment 3 replicated the results using a central reference point.

Experiment 1

In this experiment, participants were asked to watch 5 min-long video clips excerpted from commercial movies previously unknown to them. To allow future comparisons with speakers of different languages, movies were presented without soundtrack, and therefore participants had to watch carefully and try to make sense of the events in the clip without the help of linguistic cues. The task pretends to be an experimental analog of one of human's favourite pastimes: watching others and trying to understand them. After watching each clip, they performed an order judgment task. The reference frame was always the central frame of the clip, and the comparison frame was taken at ten equally spaced intervals within the clip, five before and five after the reference. Participants pressed a left or right key to give their responses, and key mapping to "before" and "after" responses was varied within-subjects.

Method

Participants

Thirty-six students of psychology at the Facultad de Psicología, Granada, Spain, took part in the study in exchange for course credit. All of them were right-handed, had normal or corrected-to-normal vision, and none of them reported to know the movies from which the experimental clips were taken.

Materials

Six 5 min-long clips were taken from commercial movies which were judged to be little known in Spain and within the context of our participant pool. The clips encompassed several scenes, across which the characters and the setting often changed. Each movie was divided into 11 equally sized intervals, from time 0 at origin until time 11 at the final frame. The frame at time 6 was taken as the reference frame, and frames 1–5 and 7–11 were used as comparison frames. No attempt was made to coordinate frame selection with event structure of the clip, that is, frames did not picture more relevant or salient events in the story: temporal position was the single selection criterion. The full set of materials used in the experiments reported hereby can be downloaded from http://medina-psicologia.ugr.es/~metproject/Santiago-EventSequences-PsychologicalResearch-Materials.zip.

Procedure

All experiments in the present investigation were designed and run using E-prime 1.0 (Schneider, Eschman, & Zuccolotto, 2002). As this version of E-prime does not support presentation of video clips, participant and experimenter sat facing two computer screens. One screen was used to show the clips, whereas the other computer ran the experiment program and was used for data collection. The participant used a keyboard for responding, and the experimenter controlled trial presentation with the mouse. One clip was always used as practice at the beginning of the session. After practice, the remaining 5 clips were presented in random order. Each clip (including the practice clip) was first viewed on one computer, and then followed by an order decision task on the other computer. Clips were played with no sound, at full screen size. The order task for each clip consisted of two blocks, which only differed in the mapping of left ("d") and right ("l") keys to "before" and "after" responses. The "d" key was covered with a sticker depicting a circle, and the "l" key was covered with a sticker depicting a cross. Keys were referred by these drawings in the instructions to participants. At the beginning of each block, participants were instructed about the mapping of keys to "before" and "after" responses that they should use during the block. Half the participants experienced first the congruent mapping ("d"-"before", "l"-"after"), then the incongruent, whereas the other half saw the opposite order. Each block consisted of 20 trials, with two presentations of each comparison frame in random order. Frames in the order comparison task were also presented at full screen size.

Within each order comparison trial, the reference frame was presented first, and remained on screen until the experimenter clicked the mouse. A fixation point was then presented for 500 ms, followed by the comparison frame which stayed on until a keyboard response was registered or 7,000 ms elapsed. Finally, there was a blank intertrial interval of 500 ms.

Design and data analysis

Keypress latencies and errors were recorded and submitted to a 10 (Position) × 2 (Response side) ANOVA taking participants as random factor.[1] The left–right effect is indexed by a significant interaction between Position and Response, such that processing of "before" comparison frames (positions 1–5) is faster and more accurate when responded to with the left key and processing of "after" frames (positions 6–10) is better when responded to with the right key.

In order to provide a more direct test of the left–right effect, a dRT measure was calculated by substracting left hand latencies from right hand latencies for each participant and frame position, and it was then submitted to linear regression using position in the sequence as predictor (following Lorch & Myers, 1990). This analysis allows a direct test of the left–right effect, which core is the expectation that the relative size of right versus left hand latencies will decrease as the sequence proceeds rightwards. The prediction is therefore that regression betas will be negative and significantly different from zero. In order to test this prediction,

[1] The counterbalancing factor was not included in the design. Although there could be interactions with this factor, they would be of no theoretical value. Counterbalancing assures that order-practice effects are controlled for. Sometimes it is useful to include it as a factor in the analyses to take off some error variance and improve the power of the analysis, but it is not necessary in the present experiments, as all ANOVAs already provide significant results for the factors of interest.

individual beta coefficients were computed and tested against zero by means of a one-tailed *t* test.

The distance effect is directly assessed in an independent ANOVA in which Position is coded as Distance from reference, averaging the two homologous positions at each side of the reference. A distance effect should show as a slower and less accurate processing of items as they get closer to the center of the sequence.

Results

The global accuracy level was moderately good (10.37% errors). The five experimental video clips produced different amounts of errors: three clips showed a very good accuracy: 7% (clip #2), 8% (clip #3), and 5% errors (clip #7), whereas one accumulated 14% errors (clip #4) and another as much as 17% errors (clip #5). These differences in accuracy suggest that it was not equally easy to learn the 5 min-long sequence of events for all clips, possibly due to uncontrolled differences in visual discriminability of frames or ease of apprehending event structure.

Latencies of correct trials were trimmed using 250 and 2,500 ms as cut-off points, what led to the rejection of 2.54% data points. These cut-off points were selected after visual inspection of the RT distribution, placing them at points that leave off extreme data but without eliminating a too high percentage of data (see Bush, Hess, & Wolford, 1993). In the following experiments, we kept the same cut-off points. All analyses from the present experiments have been carried out using both more strict and lenient cut-offs, within reasonable limits, and the pattern of results remains constant.

The ANOVA on latencies revealed a significant interaction ($F(9,315) = 2.23$, MSE = 36680.14, $p = 0.019$). As shown in Fig. 1, the shape of this interaction matches exactly the expectations from a left–right analogical representation of the video clips: latencies for positions 1–5 were faster for left hand than right hand responses, and the opposite was true for positions 6–10. There was also a significant main effect of Position ($F(9,315) = 22.59$, MSE = 12917.30, $p < 0.001$) and no overall effect of Response side ($F < 1$). The corresponding analysis of accuracy did not qualify this pattern: cell means were congruent overall with latencies, and there were no traces of speed-accuracy trade-offs (Interaction: $F(9,315) = 2.14$, MSE = 0.007, $p = 0.025$; Position: $F(9,315) = 18.20$, MSE = 0.014, $p < 0.001$; Response side: $F < 1$). Table 1 shows error means and standard deviations. Therefore, the remaining analyses were based on the latencies of correct trials.

Figure 1 also shows a clear Position effect in which judging the order of clip frames becomes more difficult as its position in the sequence gets closer to the reference point (at the center of the clip). This distance effect was directly tested in a 5 (Distance) × 2 (Response side) ANOVA, which confirmed the visual impression (Distance: $F(4,140) = 35.31$, MSE = 7785.14, $p < 0.001$; Side: $F < 1$; Interaction: $F(4,140) = 1.44$, MSE = 5855.31, $p = 0.221$).

It therefore seems that video clips are able to generate both left–right and distance effects. We submitted the left–right effect to a more direct test following the guidelines proposed by Lorch & Myers (1990). Individual regression betas were primarily negative (95% confidence interval: −0.328 to 0.092), but they failed to reach significance in a one-tailed *t* test against a zero population mean ($t(35) = -1,137$, $p = 0.131$). Under the standard interpretation, this means that the left–right effect does not generalizes enough

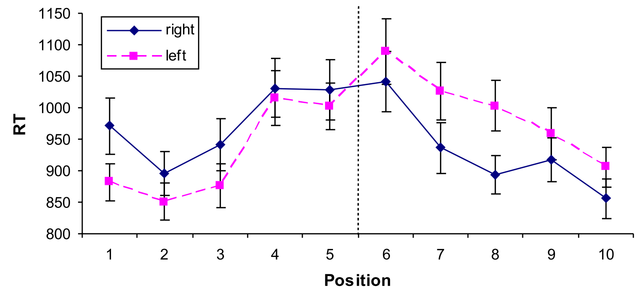

Fig. 1 Mean latencies per condition in Experiment 1, as a function of Position in sequence and Response side. Latencies are shown in milliseconds. The *dotted line* marks reference frame location in the sequence

Table 1 Mean error proportion and standard deviation (in brackets) in Experiment 1 as a function of Response side and Position

Position	Response side	
	Left	Right
1	0.06	0.09
	(0.07)	(0.09)
2	0.05	0.07
	(0.07)	(0.08)
3	0.05	0.08
	(0.07)	(0.11)
4	0.12	0.13
	(0.13)	(0.12)
5	0.20	0.25
	(0.16)	(0.14)
6	0.18	0.20
	(0.17)	(0.16)
7	0.12	0.09
	(0.12)	(0.11)
8	0.11	0.06
	(0.11)	(0.09)
9	0.08	0.05
	(0.09)	(0.07)
10	0.04	0.04
	(0.06)	(0.07)

over the sample of participants. We reasoned that perhaps the low accuracy videos were generating a different strategy for event sequence representation (one which would be not so efficient to perform the order decision task). In order to test this possibility, we repeated the analysis using only the three clips with less than 10% errors. The *t* test now approached significance ($t(35) = -1{,}475$, $SD = 0.550$, $p = 0.074$), suggesting that there is a relation between a correct performance in the order decision task and the use of a left-to-right analogical mental line to represent the sequence.

Discussion

Experiment 1 showed that both left–right and distance effects arise when people carry out order decisions on naturalistic extended scenes showing meaningfully interpretable sequences of events. This suggests that the mental representation of those scenes, when contemplated in hindsight in order to perform the order judgment task, extends from left to right along an analogical mental line. Such representation looks similar to the mental representation of numbers (Dehaene et al., 1993), months and alphabet letters (Gevers et al., 2003) and days of the week (Gevers et al., 2004). It also looks similar to the mental representation suggested for past and future times by Santiago and collaborators (Santiago et al., 2007; Torralbo et al., 2006) and for time intervals by Vallesi et al. (in press), although currently available data do not include distance effects, but only left–right effects.

Meaningful event sequences very likely constitute a qualitatively different kind within the general category of ordinal sequences. They do not have the rule-based generativity of numerical sequences, nor the overlearned nature of months or alphabet letter sequences. However, their internal structure holds their component events together by means of causal and teleological links. Five minutes long sequences containing a high number of different events performed by several characters in changing settings can be learnt and the order of events remembered to a reasonably good accuracy after a single presentation, as a consequence of the intrincate internal structure of events and subevents, goals and subgoals, that the observer weaves on-line at presentation time (Zacks & Tversky, 2001). It constitutes a somewhat surprising result that this highly structured narrative representation unfolds along an analogical spatial mental line from left to right, as this configuration does not seem to be necessary for the subsequent performance of tasks related to the visual narrative, such as order judgments. Event order could just as well be established directly from the hierarchical and logical structure of events in the sequence. It remains to be seen whether other tasks (i.e., event recognition, inference generation, etc.) are also performed through the use of this left-to-right mental line. Another question that also remains open and in need of more research concerns whether this mental line is shared with all or some of the other kinds of ordered sequences (numbers, months, events, etc., see the "General discussion" section).

However, before proceeding to these other questions, the left–right and distance effects for event sequences need to be established under more adequately controlled conditions and with a more satisfactory statistical reliability level. Using naturalistic sequences such as video clips has important implications regarding generalization of results, but at the same time, it leaves a great number of factors uncontrolled for, which might be responsible for the observed results. For example, using a fixed central frame as reference opens the possibility that primacy and recency effects operating over the whole sequence are the cause of the observed distance effect. Another troublesome factor might be sideways movement of objects and characters in the clips. If left-to-right movement of elements in the scene is more frequent than the opposite, and the order comparison task is carried out by re-viewing the clip, it might induce a Simon effect leading to the observed left–right effect (Bosbach, Prinz, & Kerzel, 2004). Other uncontrolled factors include event discriminability along the sequence, and speed of event change at different points of the story. Finally, it might be the case that the participants failed to fully capture the logical event structure of the clips (because of their length, the lack of sound, and the fact that the clips were excerpted from movies without respect to a logical structure having a meaningful beginning and end). Perhaps the difficulty of capturing event structure forced participants to rely more heavily on linearization strategies. Experiment 2 was designed to overcome all these problems.

Experiment 2

Experiment 2 used event sequences presented by means of photographs of everyday activities. A person was photographed while carrying out activities such as setting up the fireplace, preparing and leaving for a car trip, or preparing and having breakfast. All sequences had a clear beginning and end, an evident overall goal and a logical sub-goal structure. Each event sequence consisted of six photographs, which were presented at constant durations, one after another, taking up the whole screen, for a total of two presentations of the whole sequence. Participants then performed the order judgment task with both left–right congruent and incongruent response mappings.

A key manipulation in Experiment 2 consisted in the introduction of a reference point which could be independently moved to different moments in the sequence. This was a black circle centered on the screen and presented between two photographs. Participants were instructed that the subsequent order task would always consist of identifying whether a picture was presented before or after "the big dot". Reference point location was varied within-participants: in one condition (which will be called the precondition), it was located between the second and third pictures. In another condition (the Post condition), it was located between the fourth and the fifth pictures. In other words, pictures 3 and 4 occurred after the reference point in the precondition and before it in the post condition. Pictures 1 and 2 were always before the reference, and pictures 5 and 6 were always after the reference. This manipulation let us assess the left–right effect for the very same pictures in the sequence, thereby controlling for factors such as primacy and recency effects, picture discriminability, familiarity or salience.

A final change in Experiment 2 was the use of only the right hand for responding. Participants pressed the "n" and "m" keys with the index and middle fingers of the right hand to give their order judgments. We did so in order to ascertain that the relevant factor for the left–right effect in event sequences is response location and not response hand, as it has already been shown for numerical sequences (Priftis, Zorzi, Meneghello, Marenzi & Umiltà, 2006). This change also has the advantage of avoiding a concern based on the polarity-matching account proposed by Proctor & Cho (2006) for speeded discrimination tasks. Under this account, the salient pole of a stimulus dimension is more readily mapped to the salient pole of the response dimension. If future is the salient pole of the past-future dimension, and right is the salient pole of the left–right hand dimension, as it seems sensible to suppose, mapping future (or "after") onto a right hand response and past (or "before") onto a left hand response should lead to faster responding than the opposite, incongruent mapping. If index and middle finger responses are used instead, the salient pole of the response dimension is likely to be the index finger, now located on the left side. If responding is faster when "before" is mapped to the index finger and "after" to the middle finger than the opposite, polarity matching between the temporal and effector dimensions can be ruled out. Finally, this procedure should also make this task more usable for future studies with neuropsychological patients.

Method

Participants

Thirty-six participants drawn from the same population as in Experiment 1 took part in the study. They all were right-handed, and had normal or corrected to normal vision.

Materials

The event sequences of six everyday activities were used, each one composed in turn by six photographs of the same character in the same external context (a quite standard family home). The event sequences were: finding a motif and embroidering it in a baby's bib, preparing and eating breakfast, feeling cold and setting up the fireplace, doing and hanging the laundry, preparing and cooking a loaf of bread, and preparing for a car trip and leaving by car. The activities were not necessarily of high frequency in everybody's repertoires, but pilot testing showed that their internal logic and goal structure could be easily grasped after one presentation. All sequences were presented twice to make sure that everybody understood them well. Materials used in the Experiments 2 and 3 can also be accessed from http://medina-psicologia.ugr.es/~metproject/Santiago-EventSequences-PsychologicalResearch-Materials.zip.

Procedure

Each participant performed the two conditions varying in reference point location, with their order being counterbalanced over participants. Within each condition, instructions were followed by the presentation of two blocks, each one containing all six sequences. There were no practice trials. The two blocks only differed in the mapping of response keys "n" and "m" to "before the reference" and "after the reference" judgments. The order of presentation of these blocks was also counterbalanced over participants. The "n" and "m" keys were covered with the stickers of a circle and a cross, respectively, and referred by these drawings in the instructions to participants.

Within each response mapping block, the six sequences were presented in the same order, but the starting point was varied over participants: participant 1 saw the sequences 1–6, participant 2 saw the sequences 2–6 and then sequence 1, participant 3 saw the sequences 3–6 and then 1 and 2, and so on.

Finally, for each sequence, the procedure was as follows. First, the whole sequence was presented twice, at a rate of one picture per 2,000 ms. The reference point was presented between the second and third picture in the precondition and between the fourth and fifth picture in the postcondition. Then, the order judgment task was carried out. Each trial consisted of a fixation point for 500 ms followed by one of the pictures which stayed on until a response was registered, followed by a blank 500 ms intertrial interval. Each picture was presented twice, for a total of 12 trials per sequence. All pictures were presented at full screen size.

Design and data analysis

The analysis of latency and accuracy data followed the guidelines in Experiment 1. Two factorial designs were used: a 2 (Reference location) × 6 (Position) × 2 (Response side) design, and a 2 (Reference location) × 4 (Distance from reference) × 2 (Response side) design. The Distance factor was again computed by averaging homologous positions at both sides of the reference point. Note that, because the reference point is not located at the central position, the two longer distances show only the contribution of the longest side. Within-participants ANOVAs taking participants as random factor were used for statistical analyses. dRT (right minus left key) was also computed by participant and individual regression betas analyzed.

Results

The global accuracy level was quite high (2.55% errors), and similarly so for all six sequences (range 2.00–3.00%). Using the same cut-off points for outlier trimming as in Experiment 1 (250 and 2,500 ms), we rejected 0.93% of correct trials.

The ANOVA on latency data showed a significant three-way interaction between Reference location, Position and Response side ($F(5,175) = 2.95$, MSE = 4292.45, $p = 0.013$). Figure 2 shows latencies per condition. All two-way interactions were also significant (Position × Response: $F(5,175) = 8.40$, MSE = 5155.16, $p < 0.001$; Reference × Response: $F(1,35) = 11.20$ MSE = 5803.07, $p = 0.001$; Reference × Position: $F(5,175) = 8.27$, MSE = 3016.40, $p < 0.001$). Finally, only the main effect of Position was reliable ($F(5,175) = 8.43$, MSE = 4261.16, $p < 0.001$). That is, neither changing the location of the reference point nor the response side produced overall changes in latency (both Fs < 1).

In the ANOVA on accuracy data, the three-way interaction approached significance also ($F(5,175) = 1.94$, MSE = 0.001, $p = 0.088$). The only other significant results were the main effect of Position ($F(5,175) = 4.45$, MSE = 0.001, $p < 0.001$) and its interaction with Reference location ($F(5,175) = 18.28$, MSE = 0.001, $p < 0.001$). Accuracy data did not qualify the pattern of results observed in the latency measure (see Table 2), and we focused the remaining analyses on the latter.

Independent ANOVAs on the latencies within each Reference location both showed clearly significant main effects of Position and Response side, as well as their interaction (Pre location: Position, $F(5,175) = 5.91$, MSE = 3273.81, $p < 0.001$; Response, $F(1,35) = 4.78$, MSE = 3524.87, $p = 0.035$; Interaction: $F(5,175) = 2.84$, MSE = 5384.06, $p = 0.017$; Post location: Position, $F(5,175) = 10.37$, MSE = 4003.74, $p < 0.001$; Response, $F(1,35) = 7.04$, MSE = 7559.91, $p = 0.035$; Interaction: $F(5,175) = 10.01$, MSE = 4063.54, $p < 0.001$). On inspection, both panels in Fig. 2 show that latencies for each response side cross over at the location of the reference point, with the left response being faster overall for pictures before the reference and the right response being faster for pictures after the reference (the only exception being position 4 for the Pre location).

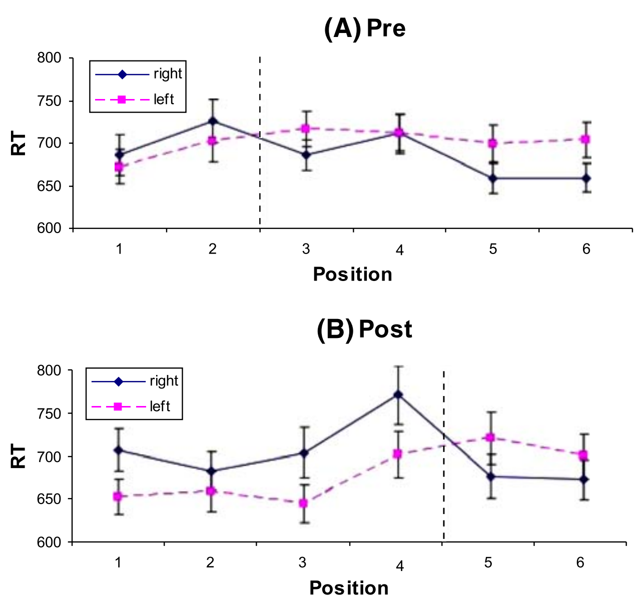

Fig. 2 Mean latencies per condition in the pre (**a**) and post (**b**) reference location conditions in Experiment 2, as a function of Position in sequence and Response side. Latencies are shown in milliseconds. Reference location is marked by a *dotted line*

Table 2 Mean error proportion and standard deviation (in brackets) in Experiment 2 as a function of Reference location, Response side and Position

	Reference location			
	Pre		Post	
Response side	Left	Right	Left	Right
Position				
1	0.05	0.02	0.01	0.02
	(0.05)	(0.04)	(0.02)	(0.03)
2	0.05	0.04	0.01	0.01
	(0.06)	(0.06)	(0.02)	(0.04)
3	0.02	0.03	0.01	0.01
	(0.04)	(0.04)	(0.02)	(0.02)
4	0.02	0.02	0.01	0.02
	(0.04)	(0.04)	(0.02)	(0.03)
5	0.02	0.02	0.04	0.03
	(0.04)	(0.05)	(0.05)	(0.04)
6	0.01	0.01	0.05	0.03
	(0.04)	(0.03)	(0.05)	(0.04)

Positions closer to the reference point also have longer latencies than positions closer to the extremes of the sequence. Therefore, there seems to be both clear left–right and distance effects in the data.

To provide a more direct test of the distance effect, a 2 (Reference location) × 4 (Distance from reference) × 2 (Response side) ANOVA was carried out. There was a clear main effect of Distance from reference ($F(3,105) = 18.62$, MSE = 2068.38, $p < 0.001$). This effect tended to level off in the longer distances, as supported by polynomial contrasts (linear: $F(1,35) = 26.91$, MSE = 3043.44, $p < 0.001$; quadratic: $F(1,35) = 21.41$, MSE = 1558.69, $p < 0.001$; cubic: $F < 1$). The analysis also revealed an interaction of Reference location and Response side ($F(1,35) = 14.32$, MSE = 5368.00, $p < 0.001$), which is due to the fact that the influence of Response side is not evenly distributed over the factor Distance in both Reference location conditions. In condition Pre, the longer distances extend into final positions in the sequence (5 and 6), whereas in condition Post, the longer distances from the reference comprise the initial positions in the sequence (1 and 2). Finally, the three-way interaction was again highly significant ($F(3,105) = 6.67$, MSE = 2461.53, $p < 0.001$). As Fig. 3 shows, this interaction is due to the difference between response sides becoming greater at longer distances from the reference.

To substantiate the left–right effect, individual regression betas were computed on dRT data (right hand minus left hand) for each participant and reference location. The resulting means are plotted in Fig. 4. Regression slopes were similar for both reference locations ($t(35) = 0.06$, $p = 0.94$). Averaged betas over reference locations were overwhelmingly negative (95% confidence interval: −0.386 to −0.082; $t(35) = -3.12$, $p < 0.01$).

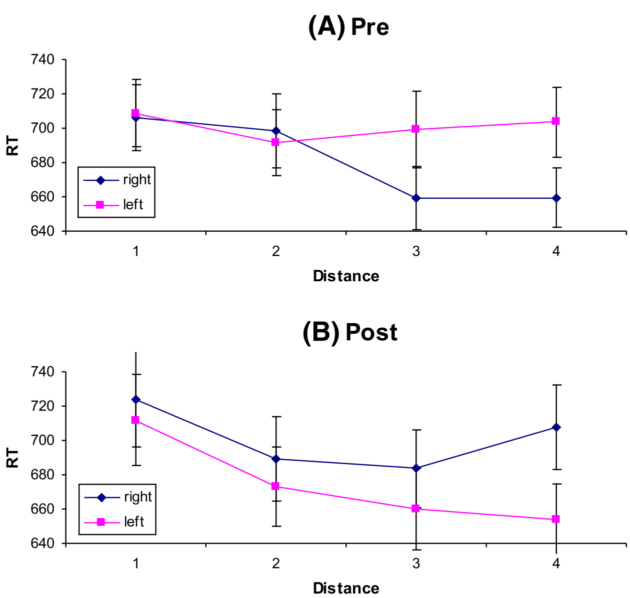

Fig. 3 Mean latencies per condition in the pre (**a**) and post (**b**) reference location conditions in Experiment 2, as a function of Distance from reference and Response side. Latencies are shown in milliseconds

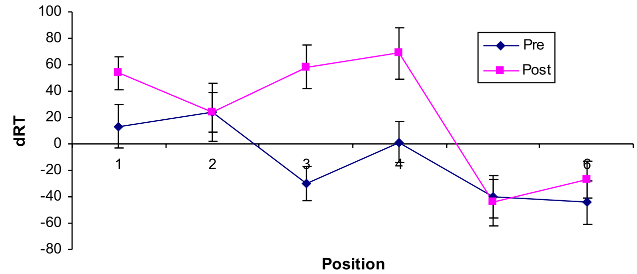

Fig. 4 Mean dRTs (right hand minus left hand) in Experiment 2, as a function of Reference location and Position in the sequence. Latencies are shown in milliseconds

As a final, but crucial test, we used dRT data to look at the central positions of the sequence (third and fourth) as a function of whether the reference point was located before or after them. Tukey's HSD post hoc comparisons for each sequential position showed that dRT differences are significant in the third position ($p < 0.003$) and approach significance in the fourth ($p = 0.085$). The contrasts for all other positions in the sequence were far from reaching significance, with all p approaching 1.

Discussion

Experiment 2 showed clear evidence for both a distance and a left–right effect. The left response was faster to indicate "before" than "after" the reference point whenever the target picture preceded that point in the sequence, and it was slower when it followed the reference. The converse occurred for the right response. Latencies also peaked at positions close to the reference point and speeded up toward the extremes of the sequence. Very importantly, order decisions for pictures located at central points of the sequence behave differently when the reference point preceded or followed them. Experiment 2 therefore provides evidence for a left–right analogical representation of meaningful event sequences without possible confoundings with factors such as event or picture discriminability, primacy or recency effects, movement direction of objects in the scene and so on. A final result from Experiment 2 is that these "mental line" effects were found when responses were given using only the index and middle fingers of the right hand. As a consequence, the important factor seems to be response side and not response hand, and the possibility of a polarity matching effect between "before" and left hand and "after" and right hand can be ruled out.

A possible complaint about this study concerns whether the nature of the sequences used may be different from those in Experiment 1. It might be argued that changing from 5 min-long movie excerpts to series of six photographs turned these sequences into something more similar to overlearned arbitrary sequences such as the months of the year or days of the week, or at least allowed participants to treat them in a similar way. We believe that this argument does not sustain, because it implies that the sequences are learned through a kind of rote memory. However, the picture sequences in Experiment 2 were rather long (six items) and were presented only twice at a moderately fast rate (2 s per picture), which does not seem enough to support a high level of on-the-spot rote learning. In contrast, participants showed a very high accuracy in making order judgments (less than 3% errors). We contend that this level of accuracy could not be attained without capturing the goal structure of the sequences during its presentation, therefore turning them into meaningful stories, held together by the apprehended hierarchical structure.

A second concern has to do with possible response biases induced by the different proportions of "before" and "after" trials in the Pre and Post versions of Experiment 2. To rule out any confounding due to response biases, Experiment 3 replicated prior results using a central reference point.

Experiment 3

Experiment 3 was a straightforward control experiment to rule out the possibility that the differing proportions of "before" and "after" responses in the Pre and Post conditions of Experiment 2 played any role in the observed results. Experiment 3 replicated the prior experiment in all respects, except one: the reference point was located in the center of the picture sequence, and there was a 50% proportion of "before" and "after" responses.

Method

Participants

A new sample of 24 participants was drawn from the same population as in prior experiments.

Materials, procedure, design and data analysis

Everything was kept exactly the same as in Experiment 2 with the sole exception of reference point location, which now occurred between the third and fourth pictures, at the central position of the sequence.

Results and discussion

Global accuracy was slightly lower (4.94% errors, range 3.38–6.25%) and there were also somewhat more outliers (2.22%). Grand average latency was slower (830 vs. 691 ms). Both indexes suggest that the task was made somewhat more difficult by having to remember three pictures at each side of the reference point, instead of 2 and 4, although at present the causes are unclear.

The ANOVA on latency data showed a two-way interaction between Position and Response ($F(5,115) = 12.38$, $MSE = 9037.23$, $p < 0.001$), and also main effects of Position ($F(5,115) = 17.90$, $MSE = 5632.25$, $p < 0.001$) and Response ($F(1,23) = 5.75$, $MSE = 6190.23$, $p = 0.024$). As shown in Fig. 5, the effect of Position and the interaction between Position and Response are again consistent with clear distance and left–right effects, and perfectly replicate the main findings of Experiment 2. Only the main effect of Response was not previously observed: participants were faster responding with the index finger, which supports the suggestion that this is the salient pole of the response dimension in this task. Accuracy data again did not qualify the latency analysis (see Table 3). Both the interaction Position × Response ($F(5,115) = 3.71$, $MSE = 0.002$, $p = 0.003$) and the main effect of Position ($F(5,115) = 3.03$, $MSE = 0.004$, $p = 0.012$) reached significance (Response: $F < 1$).

Follow up analyses of latency also replicated and extended the findings of Experiment 2. When Distance from reference was included in the design, it showed a clear main effect ($F(2,46) = 26.49$, $MSE = 4247.32$, $p < 0.001$) which did not interact with the main effect of Response ($F < 1$). This result supports our interpretation of the interaction between Distance and Response found in Experiment 2 (see above). Polynomial contrasts showed only a linear component ($F(1,23) = 48.10$, $MSE = 4459.0$, $p < 0.001$), although the quadratic was not far from significance ($F(1,23) = 2.61$, $MSE = 4035.69$, $p = 0.119$), indicating a trend to level off at longer distances. Finally, individual regression betas were again overwhelmingly negative, even more so than in Experiment 2 (95% confidence interval: −0.690 to −0.313; $t(35) = -6.75$, $p < 0.001$).

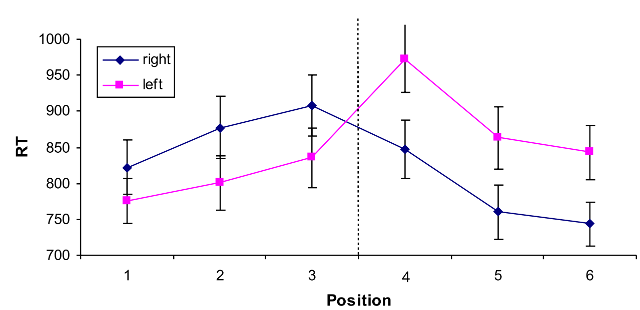

Fig. 5 Mean latencies per condition in Experiment 3, as a function of Position in sequence and Response side. Latencies are shown in milliseconds. Reference location is marked by a *dotted line*

Table 3 Mean error proportion and standard deviation (in brackets) in Experiment 3 as a function of Response side and Position

Position	Response side	
	Left	Right
1	0.02	0.04
	(0.04)	(0.05)
2	0.04	0.06
	(0.08)	(0.08)
3	0.05	0.06
	(0.09)	(0.09)
4	0.07	0.09
	(0.10)	(0.12)
5	0.05	0.03
	(0.05)	(0.07)
6	0.06	0.01
	(0.06)	(0.03)

Summing up, Experiment 3 replicated prior results in all important respects, showing clear distance and left–right effects under conditions that prevent any possible confounding due to response biases.

General discussion

The present investigation reveals several interesting points about the mental representation of witnessed meaningful event sequences. Sequences of a sizeable length can be easily and quickly learned after a short exposure. When participants must answer questions about sequential order, present results are supportive of the development of a mental representation of the sequence which places those events from left to right onto an analogical mental line. In hindsight, experienced events unfold from left to right in our mind.

Using an order decision task, Experiment 1 found left–right and distance effects for visual narratives (5 min-long silent video clips excerpted from commercial movies). Experiment 2 found similar results using sequences of six photographs depicting everyday activities. It also compared the central pictures when the reference point for the order comparison task was moved before and after them, finding clear effects linked to position relative to the reference. Finally, Experiment 3 replicated this result using a central reference point. The overall pattern of results is clear and consistent.

Across experiments, several alternative accounts were ruled out: the results are not due to primacy-recency effects; stimulus discriminability; actual or implied movement; order discriminability; or response biases. Present experiments were also able to show that the results are not exclusively due to pre-stored associations or polarity matching between the conceptual dimension and the hand response dimension.

One alternative account, though, remains to be investigated. A version of the polarity matching account may be devised such that the response dimension is conceived not as an effector dimension, but as an abstract response side dimension (left side response vs. right side response), in which right side is the salient pole. Therefore, it would be easier to map "after" (or future) to responses in the right side, and "before" (or past) to responses in the left side.

For unimanual responses we find this a remote possibility, because the index finger is the preferred finger for most, if not all, pointing and keying actions, all other factors being equal. Index finger pointing shows an impressive preponderance over other effectors from about 11 months of age on. Such a preference is probably rooted in biomechanic and evolutive factors, with ample space for socio-educational factors to push also toward selecting the index finger as the default choice for pointing (Butterworth, 2003). It may be argued that the preferred status of the index finger for pointing does not carry on to keying, but we find this possibility unlikely. If participants could just as easily choose to code their responses as either index-middle finger or left–right finger to control their keying responses, there would be no need to provide means to switch mouse buttons for left-handed people, for example. A more likely scenario is the use of the natural coding of fingers as index-middle in the present task, although nothing in the present study lets us dismiss the left–right coding with absolute certainty.

Some recent data show that congruency effects between time and the left–right spatial axis can be observed without the implication of a response dimension. Weger & Pratt (2008) and Ouellet et al. (2008) showed that processing the temporal reference (past vs. future) of a visually presented word is enough to bias a subsequent detection task in the expected direction. Ouellet et al. (2008) were able to show that the word's temporal reference has independent, additive effects on stimulus discrimination and response selection. Work on the representation of numerical sequences have also found purely attentional and perceptual left–right effects (e.g., Fischer et al., 2003; Casarotti et al., 2007; Stoianov et al., 2008; see the Introduction). However, no direct evidence is available for event sequences of the kind studied in the present investigation, so a definite answer to this question must await future experiments.

We conclude that present data are supportive of the idea that the left–right mental line is an important representational choice for sequences of meaningful events, although future studies are needed to rule out the abstract response side polarity matching hypothesis and to establish the degree of automaticity of the use of such format.

Many questions remain for future research. One of them is whether a left–right representation is the default choice for ordered sequences of all kinds, at least in readers of left-to-right orthographies (see discussion of orthographic effects below). Numerical sequences, over-learned arbitrary sequences, and meaningful event sequences, might all be represented in the mind as running along an analogical left–right mental line. A related question is whether these far-reaching left–right effects in sequence processing have to do with the use of a common underlying spatial representation. To put it in other words, the question is whether there is one or many mental lines. There are contradictory reports about whether physical line and number bisection tasks associate or dissociate in healthy participants and neglect patients (Cappelletti, Freeman & Cipolotti, 2007; Doricci, Guariglia, Gasparini, & Tomaiuolo, 2005; Longo & Lourenco, 2007; Zorzi, Priftis & Umiltà, 2002; Zorzi, Priftis, Meneghello, Marenzi, & Umiltà, 2006). Moreover, Zorzi et al. (2006) reported a dissociation between numerical and month sequences in neglect patients and Casarotti et al. (2007) found an analogous dissociation in healthy participants. After the present investigation, event sequences also enter the picture and need to be evaluated and compared with the other kinds of ordinal sequences.

A third question concerns the extent of the left–right spatialization strategy to other conceptual domains. A different kind of left–right bias which could be fruitfully related to the left–right effects found in ordered sequences has to do with the location of agents and objects of sentences in mental space. Chatterjee and co-workers (Chatterjee, Maher, Gonzalez-Rothi & Heilman, 1995; Chatterjee, Southwood & Basilico, 1999; Maher, Chatterjee, Gonzalez-Rothi & Heilman, 1995) found a tendency to locate the agent to the left of the object when hearing a transitive sentence. These authors also showed that this is a high level effect, as it is replicated with passive sentences in which the object is mentioned before the agent. In the same line, Rinaldi & Pizzamiglio (2006) showed that neglect patients tend to neglect the agent of sentences (both active and passive) when asked to point out which word in an auditorily presented sentence carried emphatic stress. More research is needed to establish the underlying commonalities between left–right biases in sentence comprehension and sequence processing.

But probably one of the chief remaining questions concerns the origins of the left–right spatialization strategy. In the context of the sentence processing effects just briefly described, Chatterjee (2001) suggested that the origin lies in hemispheric lateralization and the functional organization of the brain (see also Altmann, Saleem, Kendall, Heilman, & Rothi 2006, for a review of attentional and cognitive biases linked to each hemisphere). However, there are also hints that the cause may lie in the writing and reading conventions to which participants are exposed from early in life. One report in the literature (Maas & Russo, 2003) shows that the left–right bias in sentence comprehension reverses in Arabic readers, a right-to-left orthography, but two other studies have failed to replicate this result (Barrett, Kim, Crucian & Heilman, 2002, with right-left vertical Korean readers, and Altmann et al., 2006, with Arabic readers). In the domain of number sequences, Dehaene et al. (1993) observed a reduction and nearly a reversal of the left–right SNARC effect in a group of Arabic readers. In a more complete study which included both bilingual and monolingual Arabic speakers, Zebian (2005) was able to document a complete reversal of the SNARC effect. Finally, the only evidence available on this issue regarding event sequences comes from the Tversky et al. (1991) study, which showed that Arabic and Hebrew speaking children tended to organize stickers for events such as breakfast, lunch and dinner from right to left on a horizontal line. Definitely, more research is needed to establish the effects of the exposition to cultural habits such as direction of orthography on the mental representation of such wide and different domains as ordinal sequences and agent-object relations.

The implications of these cultural effects would be profound. Spatialization strategies are one among many ways to use concrete representations to think about more abstract terms, thereby holding the promise to help us understand how people are able to reason about things they have never seen or touched (Casasanto & Boroditsky, 2008). The analysis of patterns of linguistic usage have revealed a surprisingly wide and varied application of concrete language to talk about abstract concepts (Lakoff & Johnson, 1980, 1999), and experimental investigations about how language use affects cognition are on the rise (see Gentner & Goldin-Meadow, 2003, for an overview). This effort should now be widened to include the whole variety of cultural conventions.

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