



Left–right coding of past and future in language: The mental timeline during sentence processing

Rolf Ulrich ^{a,*}, Claudia Maienborn ^{b,**}

^a Cognitive and Biological Psychology, University of Tübingen, Friedrichstraße 21, 72072 Tübingen, Germany

^b Claudia Maienborn, German Department, University of Tübingen, Wilhelmstr. 50, 72074 Tübingen, Germany

ARTICLE INFO

Article history:

Received 14 October 2008

Revised 18 July 2010

Accepted 7 August 2010

Keywords:

Temporal cognition

Mental timeline

Metaphoric mapping theory

ABSTRACT

The metaphoric mapping theory suggests that abstract concepts, like time, are represented in terms of concrete dimensions such as space. This theory receives support from several lines of research ranging from psychophysics to linguistics and cultural studies; especially strong support comes from recent response time studies. These studies have reported congruency effects between the dimensions of time and space indicating that time evokes spatial representations that may facilitate or impede responses to words with a temporal connotation. The present paper reports the results of three linguistic experiments that examined this congruency effect when participants processed past- and future-related sentences. Response time was shorter when past-related sentences required a left-hand response and future-related sentences a right-hand response than when this mapping of time onto response hand was reversed (Experiment 1). This result suggests that participants can form time–space associations during the processing of sentences and thus this result is consistent with the view that time is mentally represented from left to right. The activation of these time–space associations, however, appears to be non-automatic as shown by the results of Experiments 2 and 3 when participants were asked to perform a non-temporal meaning discrimination task.

© 2010 Elsevier B.V. All rights reserved.

1. Introduction

Time cannot directly be experienced through our senses like, for example, a chestnut tree, because there is no adequate stimulus of time (Grondin, 2001; Woodrow, 1951). This makes time an elusive concept and thus abstract. Nevertheless, time is a ubiquitous component of our mental life that helps to structure our cognition. Thus, it is not surprising that for a long time, philosophers and psychologists have been intrigued by the question of how time is entered and represented in the cognitive system (Klein, 2009; Le

Poidevin, 2004; Roetzelein, 2000; Whitrow, 1980). According to traditional theories (e.g., Anderson, 1983; Newell, 1990), the meaning of abstract concepts emerges from their relationship to other concepts or amodal symbols within a memory system that is separated from perception and action. This traditional view has been criticized by several authors (e.g., Barsalou, 2008). For example, it has been argued that amodal symbols without any reference outside such a memory system are meaningless (Harnad, 1990). This alternative view assumes that abstract concepts need to be grounded on concrete domains, such as sensory-motor patterns, in order to gain meaning.

The idea that people use spatial representations to think and communicate about time has a longstanding tradition and can be considered common place in philosophy, linguistics, and cognitive psychology (e.g., Casasanto, Fotakopoulou, & Boroditsky, 2010; Clark, 1973; Evans, 2004; Haspelmath, 1997). According to this view, the domain of

* Corresponding author. Address: Psychologisches Institut, Universität Tübingen, Friedrichstraße 21, D-72072 Tübingen, Germany. Tel.: +49 7071 29 72410; fax: +49 7071 29 2410.

** Corresponding author.

E-mail addresses: ulrich@uni-tuebingen.de (R. Ulrich), claudia.maienborn@uni-tuebingen.de (C. Maienborn).

time is structured and conceptualized through a metaphoric mapping from the domain of space. The results of several studies examining various phenomena support the notion that people's representation of time is grounded on spatial experiences that are more concrete and richer than temporal experiences. One source of evidence for this assumption is provided by natural language. In most, if not all, languages across the world, the vocabulary of time has spatial roots, i.e., temporal expressions are derived from the inventory of spatial expressions (e.g., Clark, 1973; Haspelmath, 1997; Lakoff & Johnson, 1980; Núñez & Sweetser, 2006). For example, in the sentence "Bill was running ahead of Paul" the preposition *ahead* expresses a spatial relationship between Bill and Paul; whereas in "Bill arrived ahead of Paul" *ahead* expresses an analogous temporal relation between the two arrivals of Bill and Paul. That is, we conceive the two events as being spatially located on a one-dimensional timeline. Furthermore, in a series of experiments Boroditsky and colleagues have shown that spatial experience influences the processing of temporal information (Boroditsky, 2000, 2001; Boroditsky & Ramscar, 2002; Gentner, Imai, & Boroditsky, 2002). This kind of cross-modal priming supports the idea that thinking and speaking about time is anchored in space.

The idea that spatial representations are involved when we consider time also receives support from psychophysical studies, which investigated this relationship at a more basic level. For example, spatial attention influences the perceived duration of stimuli that appear briefly in the visual field (Mattes & Ulrich, 1998). Furthermore, when a visual object is briefly presented on a computer screen, subjects perceive the duration of the presentation as longer when the presented object is large than when it is small (e.g., Mo & Michalski, 1972; Ono & Kawahara, 2007; Xuan, Zhang, He, & Chen, 2007). In addition, this effect appears to be asymmetrical as one would expect when mental representations of time are grounded on spatial representations. Specifically, whereas spatial size influences perceived duration, perceived size is not affected by temporal duration (Casasanto & Boroditsky, 2008).

Thus, according to the metaphoric mapping assumption our thinking and speaking of time is based on a one-dimensional timeline. Does this timeline have an orientation in space? Several studies suggest that it is oriented from left to right – at least in cultures with a left-to-right writing system. Whether such a left-to-right orientation of the mental timeline is universal or rather dependent on the direction of a culture's predominant writing system has not yet been firmly established (see the discussion in Chatterjee (2001)). In one of the first studies on the mental timeline Tversky, Kugelmass, and Winter (1991) asked their subjects to associate events in time (e.g., *breakfast*, *going to bed*, etc.) with locations in space. English speakers associate early events with left and late ones with right suggesting the idea that time flies from left to right. Recent response time studies (Santiago, Lupiáñez, Pérez, & Funes, 2007; Torralbo, Santiago, & Lupiáñez, 2006; Vallesi, Binns, & Shallice, 2008; Weger & Pratt, 2008) provide especially strong evidence for a mental timeline that runs from left to right. Thus, these studies further strengthen the notion of an inher-

ent linkage between temporal and spatial concepts that follows from the metaphoric mapping account.

In the studies by Torralbo et al. (2006) and Santiago et al. (2007) on the mental timeline, single words were presented on a computer screen. These words referred either to the future or to the past (but see our criticism on the stimulus material below). More specifically, the experimental items – taken from Spanish – consisted of temporal adverbs (e.g., *ayer* 'yesterday' or *mañana* 'tomorrow'), temporal prepositions (e.g., *antes* 'before' or *después* 'after'), temporal nouns (e.g., *pasado* 'past' or *futuro* 'future'), or tensed verbs (e.g., *preguntó* '(he) asked' or *preguntará* '(he) will ask'). In one of Torralbo et al.'s experiments and in Santiago et al.'s study, subjects were asked to respond to each word with one hand if it was related to the past, and with the other hand if it was related to the future. Responses were faster when subjects had to respond with the left hand to past-related words and with the right hand to future-related words compared to a condition in which the stimulus–response (S–R) mapping was reversed.

Weger and Pratt (2008) obtained an analogous effect when subjects had to decide whether an actor became popular before or after they were born (e.g., *Charlie Chaplin* vs. *Tom Cruise*). Although the names did not convey explicit temporal information, manual responses were again shorter when the stimulus–response mapping was compatible with a left-to-right representation of time.

An analogous compatibility effect was demonstrated for non-linguistic stimuli that were explicitly related to time. In the study of Vallesi et al. (2008), the task-relevant information was the duration of a cross that was presented for either one or three seconds on a screen. As soon as the cross disappeared, subjects manually classified the duration of the cross as short or long. Responses were faster, when subjects had to respond to the short stimulus with the left hand and to the long stimulus with the right hand than when this S–R assignment was reversed. This study thus associates short durations with left and long durations with right and this corroborates the notion of a mental timeline that runs from left to right. More precisely, a short duration presumably extends mentally only across the initial (left) part of the timeline, whereas a long duration extends from the initial part to the right side.

According to Vallesi et al. (2008) the left–right congruency effect of S–R mapping observed in these response time studies (Santiago et al., 2007; Torralbo et al., 2006; Vallesi et al., 2008; Weger & Pratt, 2008) suggests that a stimulus generates a spatial response code that facilitates the overt motor response if the spatial direction of this code is congruent with the required response (for reviews see Hommel & Prinz, 1997; Umiltà & Nicoletti, 1990). Thus, when a stimulus requires a right-hand response, a future-related word or long stimulus duration will facilitate the response and thus shorten response time, because the activated response code is compatible with the direction of the required response. An analogous conclusion applies to past-related words or short stimulus duration requiring a left-hand response.

In addition, research has shown that ordinal sequences, such as numbers (Dehaene, Bossini, & Giraux, 1993), the

letters of the alphabet (Gevers, Reynvoet, & Fias, 2003) or the days of the week (Gevers, Reynvoet, & Fias, 2004) are also ordered from left to right (however, see Price & Mentzoni, 2008). Furthermore, research employing material of event sequences in natural scenes has provided evidence that mental representations of such sequences unfold from left to right in our minds (Santiago, Román, Ouellet, Rodríguez, & Pérez-Azor, 2010). These additional results are clearly supportive for the notion that a static mental timeline is involved in several cognitive functions making it unlikely that this timeline merely represents an epiphenomenon.

From a linguistic point of view, the findings in Santiago et al. (2007), Torralbo et al. (2006), and Weger and Pratt (2008) which suggest a left–right mapping of time in language are somewhat surprising and deserve further investigation. While virtually all languages have explicit spatial means to refer to time (see above), there appears to be no single language that uses the concepts of left and right for the expression of time. That is, while we frequently find expressions like “the day before Christmas”, no case of an expression like “the day to the left of Christmas” is attested across the languages of the world (e.g., Haspelmath, 1997; Radden, 2004). In his crosslinguistic survey of spatial metaphors of time, Radden (2004, p. 228) therefore concludes: “the lateral axis with a left–right orientation [...] does not seem to offer any sensible spatial basis for our understanding of time at all.” (see also Haspelmath, 1997, p. 22). The studies by Santiago et al. (2007), Torralbo et al. (2006), and Weger and Pratt (2008) suggest that this conclusion might have been premature. Rather, the above mentioned studies provide first evidence that the expression of time in language refers to the left–right axis not overtly but implicitly, at a deeper level of meaning representation. That is, a left–right-mapping of temporal expressions suggests that the metaphorical mapping from space to time takes place at the conceptual level rather than at the level of linguistic expressions.

The experiments reported in this study were designed to gain further insights into the linguistic relevance and conceptual basis of a mental timeline. While previous response time studies have demonstrated a left–right mapping of temporal expressions at the word level using isolated lexical items, we extend these studies to the processing of complete sentences. The use of sentences instead of words as test items is motivated by some linguistic concerns we have with the stimulus materials used by Santiago et al. (2007) and Torralbo et al. (2006). As mentioned above, they chose their test material from different word classes. About 25% of the experimental items belong to the class of adverbs. Among these there are two pairs that are word class ambiguous: *antes* ‘before’ vs. *después* ‘after’ also belong to the class of temporal prepositions and *pasado* ‘past’ vs. *futuro* ‘future’ may also be classified as temporal nouns. The overwhelming rest of experimental items are inflected verbs either in future or in past tense. Our first concern with this selection is that it neglects the different ways that verbs, adverbs, prepositions, or nouns are related to time. For instance, while a temporal preposition expresses a *temporal relation* that holds between two arguments, a temporal noun such as

(*the*) *past* or (*the*) *future* may be argued to refer to a certain *time interval* on the mental time line. Moreover, tensed verbs such as those used by Santiago et al. and Torralbo et al. refer to *events* that are located on the mental timeline. That is, these different word classes evoke clearly distinct modes of time reference and should better not be mixed up when examining the linguistic relevance of a mental timeline.

Secondly, not all of Santiago et al.’s (2007) and Torralbo et al.’s (2006) experimental items are past- or future-related. Among the adverbs there are several exemplars that do not express a deictic notion, i.e. reference to times earlier or later than NOW (as, e.g., *ayer* ‘yesterday’ vs. *mañana* ‘tomorrow’), but rather they involve the notion of anteriority or posteriority, i.e., reference to one time as being earlier or later in a sequence than another (e.g., *antes* ‘before’ vs. *después* ‘after’ or *anteriormente* ‘previously’ vs. *posteriormente* ‘subsequently’; see also the discussion in Núñez & Sweetser, 2006, on the confusion of futurity with posteriority).

Thirdly and most importantly, the tensed verbs such as *preguntó* ‘(he) asked’ vs. *preguntará* ‘(he) will ask’, that constitute the great majority of Santiago et al.’s (2007) and Torralbo et al.’s (2006) stimulus material, might appear as single words but they are, no doubt, sentential units consisting of a (dropped) pronominal subject and a past- or future-related predicate. Hence, rather than using words, i.e., lexical items, Santiago et al. and Torralbo et al. most of the time happen to test either complete or incomplete sentences (depending on whether they use intransitive or transitive verbs).

In sum, the stimulus material used by Santiago et al. (2007) and Torralbo et al. (2006) turns out to be rather heterogeneous, confounding word classes, semantic categories, and lexical vs. sentential units. In order to put Santiago et al.’s and Torralbo et al.’s claim that past- and future-related expressions are mapped onto a mental timeline running from left to right on a more solid empirical and methodological basis, we used uniformly past- vs. future referring sentences rather than single words as stimulus materials for our experiments. Besides the linguistic arguments presented above for the usage of sentences in the present experiments, neuro-cognitive research (Raposo, Moss, Stamatakus, & Tyler, 2009) has shown that the activation of motor and premotor cortices in the processing of certain words is reduced when these words are embedded in sentences rather presented alone. Therefore, the study of Raposo et al. (2009) suggests that the previous RT results concerning the mental timeline may not generalize to the level of sentence processing.

A second major objective of our study was to examine whether sentence processing automatically activates the mental timeline, which is an unsettled issue (see Santiago et al., 2007; Weger & Pratt, 2008). Such activation could be seen as analogous to the Simon effect (Simon & Rudell, 1967) and the SNARC effect (Spatial Numerical Association of Response Codes; Dehaene et al., 1993), in which task-irrelevant stimuli influence the speed of the response. Analogous to the SNARC paradigm, Experiments 2 and 3 in this study required participants to judge whether sentences were sensible or not. In such a setting, the temporal

reference of a sentence is not relevant to the task. If temporal linguistic information nonetheless influences RT performance in this task, this would clearly suggest that processing of linguistic information automatically activates the mental timeline and thus provide evidence for the notion that activation of this timeline is functionally involved in the processing of a sentence's content.

2. Experiment 1

Experiment 1 examined whether participants can classify the temporal reference of a sentence faster when the stimulus–response (S–R) assignment is congruent with the assumed mental left-to-right representation of time. This experiment combines the approach of the previous response time (RT) studies (e.g., Santiago et al., 2007) with the sensibility judgment task used by Glenberg and Kaschak (2002). In each trial of the present experiment, a sentence that either referred to the past or to the future was presented to a participant on a computer screen. In the congruent condition, the participant responded with a left-hand keypress to sentences referring to the past and with a right-hand keypress to sentences referring to the future. In the incongruent condition, this assignment was reversed, that is, participants responded with their left hand to a future-related sentence and with the right hand to a past-related sentence. Reference to past or future was established via tense and/or temporal adverbials. Like in Glenberg and Kaschak's study, nonsensical sentences (i.e., sentences which were grammatically well-formed but semantically deviant) were presented in some trials and participants were to refrain from responding in this case. This assures that participants process the content of a sentence. Nonsensical sentences also referred either to the past or to the future. One third of all sentences were construed as nonsensical (see Table 1). If the left–right compatibility effect reported by Torralbo et al. (2006) and Santiago et al. (2007) generalizes to the processing of complex linguistic structure (e.g., complete sentences), RT should be shorter for the left/past–right/future mapping than for the left/future–right/past mapping.

2.1. Method

2.1.1. Participants

Eleven male and nineteen female volunteers participated in a single 30-min session as partial fulfillment of course requirements or for a payment of 4 €. Their mean age was 25.3 years ($SD = 3.8$ years) and all but two reported to be right-handed. All of them were native speakers of German.

2.1.2. Apparatus and stimuli

Sentences were presented in black against a white background in the middle of a computer screen (standard VGA screen, 150 Hz), using 15 point Arial font. The experiment was programmed in Matlab® using the Psychophysics Toolbox 2.54 (Brainard, 1997; Pelli, 1997). The left and right shift key of the computer keyboard served as re-

Table 1

Example sentences used in Experiment 1. (English translations are given by interlinear word by word glosses and by normal translation.)

Type	Examples
SP	a. Hanna reparierte gestern das Fahrrad. Hanna repaired yesterday the bike (Yesterday, Hanna repaired the bike.)
	b. Karl hat den Arbeitsvertrag unterschrieben. Karl has the contract signed (Karl has signed the contract.)
	c. Mona und Diana tanzten die ganze Nacht. Mona and Diana danced the whole night (Mona and Diana danced the whole night through.)
SF	a. Morgen früh unterschreibt der Chef den Antrag. Tomorrow morning signs the boss the application (The boss will sign the application tomorrow morning.)
	b. Tim wird Rosa morgen beim Kaffee alles sagen. Tim will Rosa tomorrow at the coffee all say (Tim will tell Rosa everything tomorrow during coffee.)
	c. Wir werden in fünf Minuten in Bonn aussteigen. We will in 5 minutes in Bonn get off (We will get off in Bonn in 5 minutes.)
N	a. Die Tannen haben sich badend ihren Mantel angezogen. The fir trees have refl swimming their coat put on (The fir trees have put on their coat while bathing.)
	b. Nächsten Sonntag heiratet das Rathaus die Erbse. Next Sunday marries the town-hall the pea (On next Sunday, the town-hall will marry the pea.)
	c. Die Lautstärke fährt morgen früh nach Rom. The sound volume drives tomorrow early to Rome. (The sound volume will drive to Rome tomorrow morning.)

sponse keys. The experiment was run in a sound-attenuated, dimly illuminated room.

2.1.3. Procedure

A single trial started with the presentation of a fixation cross (i.e., a plus sign) in the middle of the screen for 200 ms. The interval between the offset of the fixation cross and the onset of the sentence was 500 ms. With equal probability, the sentence was either sensible and its content related to the past (SP), sensible and its content related to the future (SF), or its content was nonsensical (N). Half of the nonsensical sentences referred to the past and the other half to the future. In the congruent condition, participants pressed the left shift key with their left index finger in response to SP and the right shift key with their right index finger in response to SF. In the incongruent condition, this assignment was reversed. Participants were instructed to refrain from pressing a key when the sentence's content was nonsensical. The response of the participant terminated

Table 2

Sentence statistics (mean and standard deviation) for Experiments 1–3 and for each experimental condition (i.e., N, NP, NF, SP, and SF). Condition words per sentence characters per sentence word length.

Condition	Words per sentence		Characters per sentence		Word length	
	Mean	SD	Mean	SD	Mean	SD
<i>Experiment 1</i>						
N	7.4	1.1	48.3	4.9	5.6	0.8
SP	7.0	1.1	46.2	4.8	5.7	0.9
SF	7.9	0.9	49.0	5.6	5.2	0.6
<i>Experiment 2</i>						
NP	7.4	1.0	49.1	4.3	5.7	0.9
NF	7.9	1.1	50.7	4.0	5.6	0.8
SP	11.0	1.3	47.6	5.2	5.6	0.9
SF	12.3	1.1	50.1	5.4	5.2	0.7
<i>Experiment 3</i>						
NP	9.7	1.0	64.0	6.3	5.7	0.7
NF	9.7	1.0	64.7	6.0	5.6	0.7
SP	10.0	1.1	64.2	5.0	5.6	0.7
SF	10.0	1.1	66.6	6.6	5.6	0.7

Note: Characters per sentence = all characters of a sentence with blanks between adjacent words.

the presentation of the sentence. If the participant did not respond within an interval of 4 s following the onset of the sentence, the computer terminated the presentation of the sentence. In case of an error (i.e., responding with the wrong key or responding to a nonsensical sentence) a beep provided error feedback at the end of the trial. Two seconds after the termination of the trial, the next trial was initiated by presenting the fixation cross again.

Half of all participants started with the congruent condition and switched to the incongruent condition half-way through the experimental session. The other half of the participants proceeded in the reverse order. The same set of sentences was employed in both conditions. There were 40 SP-sentences, 40 SF-sentences, and 40 N-sentences. Thus, each mapping condition (i.e., the congruent and the non-congruent condition) was comprised of 120 trials. The first 10 trials in each condition were considered practice and thus were not entered into data analysis. Table 1

contains a representative sample of the sentences used in the experiment. In constructing the sentences, we made every effort to equalize the mean number of words per sentence, the mean number of letters per word, and the mean number of total ASCII characters (including blanks) per sentence across the three sets of sentences (see Table 2). Participants received written instructions before the experiment and they got additional instruction on the computer screen before switching to the second condition. Participants were left naïve as to the experimental hypothesis.

To assess the influence of possible outliers on RT results, we conducted separate analyses on RT. The first analysis used all trials (except the first 10 trials per block) for computing the mean RT in each cell of the design. The second analysis employed the median RT instead of the mean RT. The third analysis used a trimmed mean RT, in which the 5% fastest and the 5% slowest responses in each experimental cell of each participant were omitted from computing the mean RT. Since the results of these three analyses were virtually identical, we will only report the results on the (untrimmed) mean RT.

As the same sentences were used in the two congruency conditions, there was no need to control for item variance by statistical procedures. Accordingly, in analyzing our results, we performed a standard RT analysis, with subjects being the only random effects factor, as has been suggested by Raaijmakers, Schrijnemakers, and Gremmen (1999, p. 421); see also Raaijmakers (2003).

2.2. Results and discussion

Participants correctly refrained from responding when an N-sentence appeared on the screen in 95.7% of all N-trials. Furthermore, when a sensible sentence was presented, participants pressed the correct key in 94.4% of the trials.

Fig. 1 depicts the data of major interest. RT was submitted to an Analysis of Variance (ANOVA) with the within-subjects factors hand (left vs. right) and temporal reference (past vs. future), and the between-subjects factor order of conditions (congruent–incongruent vs. incongruent–con-

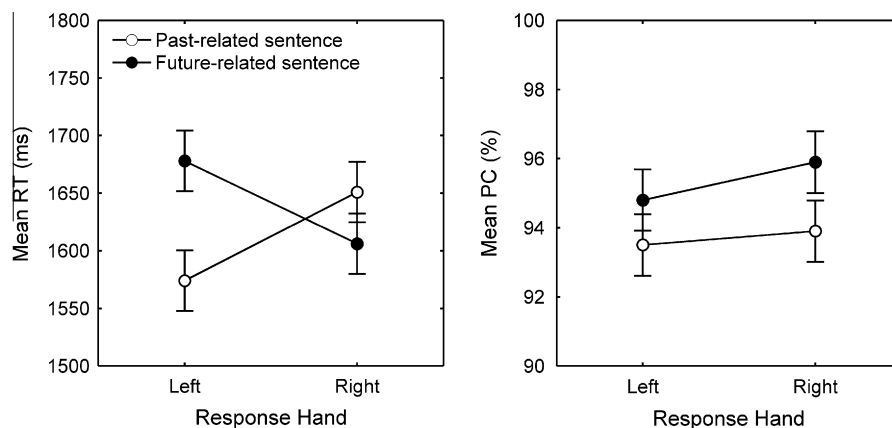


Fig. 1. Mean RT (left panel) and percentage of correct responses (right panel) as a function of response hand and temporal reference for Experiment 1. The standard error SE of the mean was computed from the mean square error *MSE* for the interaction of factor response hand and temporal reference as recommended by Loftus and Masson (1994) and Masson and Loftus (2003). Note that this standard error is particularly appropriate for assessing the interaction of these two factors. Each point shows Mean \pm 1-SE.

gruent). The overall mean RT was 1627 ms. Consistent with the above hypothesis a significant congruency effect emerged, which is reflected in a significant interaction of the factors hand and temporal reference, $F(1, 28) = 8.03$, $MSe = 20684.8$, $p < 0.01$, $\eta^2 = 0.22$. Participants responded quicker to SP-sentences with their left than with right hand (1574 vs. 1651 ms), whereas they responded faster to SF-sentences with their right than their left hand (1606 vs. 1678 ms).¹ Neither the main effect of hand, $F(1, 28) = 0.03$, $MSe = 4249.2$, $p = 0.84$, $\eta^2 = 0.00$, nor of temporal reference, $F(1, 28) = 3.41$, $MSe = 10529.9$, $p = 0.08$, $\eta^2 = 0.11$, was reliable, though there was a tendency toward longer RTs for SF- than for SP-sentences (1642 vs. 1613 ms), an effect that was also observed by Torralbo et al. (2006) with single words. Order of conditions produced no significant main effect, $F < 1$. This factor, however, modulated the interaction of hand and temporal reference, $F(1, 28) = 152.68$, $MSe = 20684.8$, $p < 0.01$, $\eta^2 = 0.85$. This three-way interaction simply reflects a practice effect, as participants responded quicker in the second than in the first part of the experiment. There were no further significant results. A second ANOVA was performed on the percentage of correct (PC) responses, that is, on the performance of correctly classifying SF- and SP-sentences. This analysis only revealed a marginally significant main effect of temporal reference, $F(1, 28) = 3.19$, $MSe = 18.6$, $p = 0.09$, $\eta^2 = 0.10$, that is, participants were more accurate when they had to respond to a SF- than to a SP-sentence.

In sum then, the experiment clearly showed that participants produce faster responses when the response assignment is congruent with the mental timeline. Specifically, when a past-related sentence required a left-hand response and a future-related sentence required a right-hand response, mean RT was shorter than when the response assignment was reversed. The additional finding that participants responded faster to SP than to SF sentences may reflect a trade-off between speed and accuracy, since percentage of errors and response speed was negatively associated. This effect, however, does not weaken the main conclusion of this experiment: The left–right effect on temporal expressions found by Santiago et al. (2007) and Torralbo et al. (2006) can be reaffirmed at sentence level.

3. Experiment 2

The major result of Experiment 1 is consistent with a mental left-to-right representation of time. Nevertheless, this result does not reveal the underlying cognitive mechanism that produces this congruency effect. There are at least two alternative accounts that can explain this effect. The first alternative assumes that participants can remember the S–R assignment in the congruent condition more easily than in the incongruent condition. Perhaps people's memory about how the temporal reference of the sentence is assigned to response hands (S–R coding) is facilitated in the congruent condition. That is, people may memorize the S–R assignment more easily when future is mapped onto

the right than onto the left. According to this memory account, then, S–R coding is well-organized in the congruent condition implying a faster response selection in the congruent condition. A similar prediction follows from Proctor and Cho's (2006) polarity hypothesis, which postulates that the selection of a response is especially efficient when salient features of a stimulus (e.g., past and future) and the associated responses (e.g., left and right) correspond.

According to a second alternative, the temporal reference of a sentence may produce automatic response activation. More precisely, temporal information about the future may automatically activate the right body space, whereas temporal information about the past may automatically activate the left body space. Consistent with the major result of Experiment 1, faster responses should be observed in the congruent than in the incongruent condition.

This automatic-activation account suggests that the mechanism underlying the congruency effect in Experiment 1 resembles the one that underlies the so-called SNARC effect (Dehaene et al., 1993). According to this latter effect, the perception of numbers elicits spatial codes that are associated with the magnitude of the number (see Hubbard, Piazza, Pinel, & Dehaene, 2005). Dehaene et al. (1993) had participants perform a parity judgment task (odd vs. even) in a bimanual response setting. Although magnitude information is irrelevant to perform this judgment, relatively small numbers were responded to faster with the left hand and relatively large numbers were responded to faster with the right hand (Dehaene et al., 1993). This effect has usually been interpreted in terms of automatic response activation arguing that small numbers prime the left whereas larger numbers prime the right response.

Experiment 2 was designed to discriminate between the memory/salience account and the automatic-activation account. In this experiment, participants performed a judgment only about the content of a sentence (Does it make sense or not?) but not about its relation to the past or the future. Therefore, the temporal information of the sentence was no longer directly relevant for selecting the correct response as in the previous experiment. Nevertheless, if meaning is action-based inducing automatic response activation, SP sentences should be easier to classify as sensible when participants are required to press the left key rather than the right key in response to sensible sentences. Analogously, processing of SF sentences should be facilitated when they have to press the right rather than the left key in response to sensible sentences. By contrast, if the congruency effect is the signature of an improved S–R coding that facilitates response selection, one would expect that the design of this experiment eliminates the congruency effect observed in Experiment 1, because the temporal reference of the sentence is no longer a relevant dimension for determining the response hand.

3.1. Method

3.1.1. Participants

Sixteen males and 54 females participated in a single session (mean age = 22.5 years, $SD = 3.6$ years). None of these 70 students had participated in the previous experiment.

¹ The statistical reliability of this interaction effect was confirmed by a F2-analysis that treated items as the only random factor, $F_2(1, 78) = 23.6$, $MSe = 5841.4$, $p < 0.001$.

Seven of them claimed to be left-handed. Participants received either course-credit or 7 €. The experiment lasted approximately 50 min. The results of three participants had to be replaced by the results of three additional participants, because their overall error rate was too high.

Table 3

Example sentences used in Experiment 2. (English translations are given by interlinear word by word glosses and by normal translation.)

Type	Examples
SP	See Table 1
SF	See Table 1
NP	<p>a. Sorgfältig strich Walter gestern seine Müdigkeit an. Carefully painted Walter yesterday his tiredness part (Walter painted carefully his tiredness yesterday.)</p> <p>b. Der Vorhang ist ganz schläfrig nach Italien abgereist. The curtain has very dozily towards Italy departed (The curtain departed very dozily towards Italy.)</p>
NF	<p>a. Morgen küsse ich endlich die flüssige Eisdiele. Tomorrow kiss I finally the liquid ice cream parlor (Tomorrow I will finally kiss the liquid ice cream parlor.)</p> <p>b. Gleich wird das Echo die Öllampe anzünden. In a moment will the echo the oil lamp light up (In a moment the echo will light up the oil lamp.)</p>

3.1.2. Apparatus and stimuli

The number of sentences was increased from 120 to 240; there were now 60 SP, 60 NP, 60 SF, and 60 NF sentences. As before, we tried to equate the mean word length, the mean number of words per sentence, and the mean number of total ASCII characters per sentence across the four sets of sentences (see Table 2). Table 3 contains example sentences. The apparatus was identical to the one in the previous experiment.

3.1.3. Procedure

Except for the following changes, the procedure was identical to the one of Experiment 1. First, in each trial and with equal probability, the sentence was either of type SP, SF, NP, or NF. Participants were asked to press one key if the content of a sentence was sensible (SP or SF) and another key if the content was nonsensical (NP or NF). Note that there were no Nogo-trials in this experiment. Second, a single session consisted of two blocks of 240 trials each. The same set of 240 sentences was employed in each single block, that is, each sentence in this set occurred randomly in one of the 240 trials of a block. Third, the assignment of the two response keys was switched between the first and the second block. Half of all participants were asked in the first block to press the left shift key if a sentence was sensible and the right shift key if its content was nonsensical. This assignment was switched in the second block. The other half of participants proceeded in the reverse order. As before, the first 10 trials in each block were considered practice and did not enter into the data analysis.

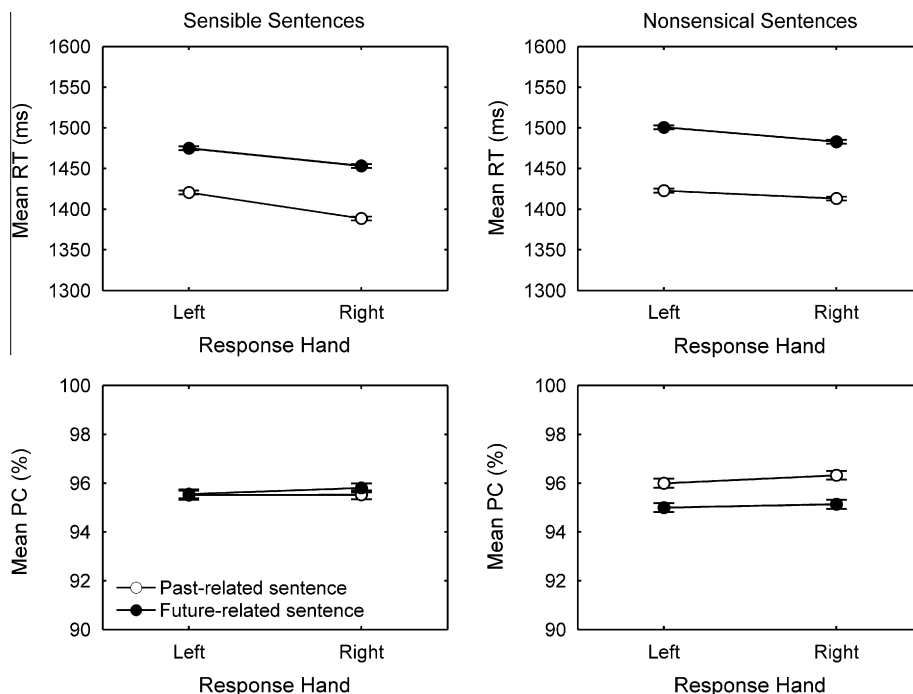


Fig. 2. Mean RT and percentage of correct responses as a function of response hand and temporal reference for Experiment 2, separately for sensible sentences (left panels) and nonsensical sentences (right panels). The standard error SE of the mean was computed from the mean square error *MSE* for the interaction of factor response hand and temporal reference as recommended by Loftus and Masson (1994) and Masson and Loftus (2003). Note that this standard error is particularly appropriate for assessing the interaction of these two factors. Each point shows Mean \pm 1 *SE*.

To assess the influence of possible outliers on RT results, mean RT, median RT, and trimmed mean RT were again analysed in separate ANOVAs. Since the results were quite stable across these three analyses, we again only report the results on the (untrimmed) mean RT.

4. Results and discussion

Fig. 2 summarizes the results of major theoretical interest. It displays mean RT and percentage of correct responses as a function of response hand and temporal reference of a sentence. Separate ANOVAs with the three within-subjects factors temporal reference (past vs. future), response hand (left vs. right), and sentence content (sensible vs. nonsensical), and the between-subjects factor order of conditions (congruent–incongruent vs. incongruent–congruent) were performed on mean RT and on PC.

First of all, the overall mean RT was 1445 ms and thus shorter than the overall mean of 1627 ms in Experiment 1, although the level of response accuracy was about the same in the two experiments (Fig. 2). This RT difference probably reflects the fact that participants were only required to assess the meaning of each sentence in Experiment 2, whereas in Experiment 1 they were required to assess both the meaning and the temporal reference of each sentence before they could launch a correct response. Like in Experiment 1, RTs were shorter for past-related than for future-related sentences, even though the temporal reference of the sentence was not a relevant dimension for selecting the response, $F(1, 68) = 253.9$, $MSe = 2444.2$, $p < 0.01$, $\eta^2 = 0.79$; this difference could be attributed to the average number of words per sentence, because this average was slightly larger for future-related than for past-related words (see Table 2). Participants produced quicker responses with the right than with the left-hand, $F(1, 68) = 14.0$, $MSe = 4093.0$, $p < 0.01$, $\eta^2 = 0.17$. Theoretically most importantly, however, response hand and temporal reference produced virtually additive effects, $F(1, 68) = 0.03$, $MSe = 1575.9$, $p = 0.866$, $\eta^2 = 0.00$. This lack of an interactive effect provides evidence against the automatic response activation account. Furthermore, the interaction between sentence content and temporal reference revealed a statistical trend, $F(1, 68) = 3.07$, $MSe = 2337.5$, $p = 0.084$, $\eta^2 = 0.04$; temporal reference produced a somewhat smaller effect on RT for sensible than for nonsensical sentences. Finally, there was a significant three-way interaction of content, hand, and group, $F(1, 68) = 146.8$, $MSe = 70536.5$, $p < 0.01$, $\eta^2 = 0.68$. Like in Experiment 1, this triple interaction merely reflects a practice effect because the order of the two S–R mappings was different for the two groups. There were no further significant effects.

Although the level of response accuracy was virtually identical in all conditions, an ANOVA on PC revealed some significant effects. First, there was a reliable main effect of temporal reference, $F(1, 68) = 4.34$, $MSe = 7.0$, $p = 0.04$, $\eta^2 = 0.10$, indicating slightly more correct responses for past-related (95.8%) than for future-related (95.4%) sentences. Second, this effect applied only to nonsensical sentences, $F(1, 68) = 12.4$, $MSe = 4.5$, $p < 0.01$, $\eta^2 = 0.16$. Factors content, hand, and group again produced a significant yet

negligible small practice effect on PC, $F(1, 68) = 17.1$, $MSe = 9.6$, $p < 0.01$, $\eta^2 = 0.98$.

In sum, the results of Experiment 2 are consistent with the memory account of the left–right congruency effect observed in Experiment 1. In line with this account, the left–right mental timeline seems to facilitate the S–R coding for selecting the appropriate response but does not automatically do so in this experiment. Because the present experiment has a higher statistical power than the previous experiment (i.e., the number of participants was increased from 30 to 70), we conclude that there was little or no left–right congruency effect in this experiment. This conclusion was strengthened by an additional ANOVA that included the data from both experiments. The results of this ANOVA revealed that the interaction of hand and temporal reference changed from Experiments 1 to 2, $F(1, 96) = 17.90$, $MSe = 6591.2$, $p < 0.01$, $\eta^2 = 0.98$. In addition, the contrast of the four cell means related to the hand \times time interaction was virtually equal to zero (i.e., 0.5 ± 4.7 ms) in Experiment 2. By comparison, the corresponding contrast in Experiment 1 was 74.5 ± 37.1 ms. We also performed a power analysis, employing an effect size of approximately 0.5 for the congruency effect in Experiment 1 as a benchmark. Given this effect size, the probability of obtaining a significant effect (i.e., the statistical power) in Experiment 2 was computed to be 99.3% (see Mayr, Erdfelder, Buchner, & Faul, 2007; but also see Miller, 2009, for a critical review of estimating the statistical power on the basis of observed effect sizes). Therefore, it seems unlikely that we have missed a left–right congruency effect of any important size in Experiment 2.

5. Experiment 3

The third experiment was designed to examine a possible alternative explanation why no congruency effect emerged in Experiment 2. It is conceivable that the activation of the left or right body space by temporal information is short-living and thus will have decayed by the time when subjects produce their response after having read the complete sentence (see Taylor & Zwaan, 2008). Although this idea seems not well supported by the data of Experiment 2 since subjects tended to produce shorter RTs in Experiment 2 than in Experiment 1, a stronger test of this proposal is still possible. In order to enable such test, Experiment 3 employed different sentences than Experiments 1 and 2. Specifically, words that carry temporal information about past or future were moved toward the end of a sentence in Experiment 3 note that this information was on average in the middle of a sentence in the previous two experiments. Therefore, if temporal sentence information produces a transient activation of the left or right body space, one should observe an influence of this activation when it overlaps temporally more strongly with response selection.

5.1. Method

5.1.1. Participants

One hundred and eighteen students participated in a single session lasting about 45 min. The data of 18

participants were discarded from data analysis because their average error rate was above 10%. The remaining pool of participants consisted of 76 females and 24 males (mean age = 23.6 years, $SD = 4.4$ years). None of these 100 students had participated in one of the previous two experiments. 11% of them claimed to be left-handed. Participants received either course-credit or 8 €.

5.1.2. Apparatus and stimuli

The apparatus was identical to the one in the previous experiment. New sentences were employed in this experiment. The number of sentences was increased from 120 to 320 per participant; there were now 60 SP, 60 NP, 60 SF, 60 NF, and 80 filler sentences. The filler sentences contained temporal information in the middle rather than at the end of a sentence in order to conceal the purpose of this experiment to the participants. We carefully equated mean word length, mean number of words per sentence, and mean number of total ASCII characters per sentence across the four sets of sentences (see Table 2). Table 4 contains example sentences. To avoid the repetition of a single sentence for the same participant, sentences were divided into two lists A and B such that none of the 320 sentences were presented two times to a single participant. However, both lists contained the same number of sentences with respect to type of sentence (i.e., 60 SP, 60 NP, 60 SF, 60 NF, 20 SP fillers, 20 NP fillers, 20 SF fillers, and 20 SP fillers). The various possible arrangements of the two lists A and B were completely counterbalanced across participants.

5.1.3. Procedure

The time course of a single trial was exactly identical to Experiment 2. A single session consisted of two blocks with 160 trials each (i.e., 30 SP, 30 NP, 30 SF, 30 NF, 10 SP fillers, 10 NP fillers, 10 SF fillers, and 10 SP fillers). As in Experiment 2, participants were asked to press one key if the content of a sentence was sensible (SP or SF) and another key if the content was nonsensical (NP or NF). The assignment of the two response keys was switched between the first and the second block. Consistent with the data analysis in the preceding experiments, the first 10 trials in each block were considered practice and thus not entered into the data analysis. Furthermore, trials with filler items were also discarded from data analysis.

5.2. Results and discussion

The percentage and mean RT of correct responses was 95.1% and 2155 ms, respectively (Fig. 3). Although overall mean RT is clearly longer in this experiment than in the previous one (1445 ms), the percentage of correct responses was virtually identical to the one in the previous experiment. This increase in overall RT can be attributed to the average length of sentences in Experiment 3, which increased by 51.5% from Experiment 2 to 3.

The overall RT from Experiment 2 to 3 increased by nearly the same percentage, that is, 49.1%.

Like in Experiment 2, RTs tended to be shorter for past-related (2148 ms) than for future-related (2162 ms) sentences, $F(1, 96) = 8.07$, $MSe = 4480.4$, $p < 0.001$, $\eta^2 = 0.08$. In addition, RT was significantly shorter for sensible

Table 4

Example sentences used in Experiment 3. (English translations are given by interlinear word by word glosses and by normal translation.)

Type	Examples
SP	a. Wie dumm, dass Charlotte den Ehevertrag unterschrieben hat. How stupid that Charlotte the matrimonial agreement signed has (How stupid that Charlotte has signed the matrimonial agreement.)
	b. Klar, dass Onkel Egon die doppelte Portion Eis gegessen hat. Clear that uncle Egon the double portion icecream eaten has (It goes without saying, that uncle Egon has eaten twice as much ice cream.)
	c. Lars schrieb für Anna ein schönes Liebesgedicht. (filler sentence) Lars wrote for Anna a nice love poem (Lars wrote a nice love poem for Anna.)
SF	a. Wie unvernünftig, dass Karl den Arbeitsvertrag unterschrieben hat. How unreasonable that Karl the labor contract signed has (How unreasonable that Karl has signed the labor contract.)
	b. Klar, dass das Kind bei der Oma nur Schokolade essen wird. Clear that the child at the grandmother's only chocolate eat will (Obvious that the child will only eat chocolate at its grandmother's.)
	c. In den folgenden Nächten schlafe ich im Hotel. (filler sentence) In the following nights sleep I in the hotel (I'm going to spend the following nights at the hotel.)
NP	a. Wie ungesund, dass Gisela die Sachertorte unterschrieben hat. How unhealthy that Gisela the Sacher cake signed has (How unhealthy that Gisela has signed the Sacher cake.)
	b. Klasse, dass Annas Bruder das alte, klapprige Auto geerntet hat. Great that Anna's brother the old rattly car harvested has (Great that Anna's brother has harvested the old rattly car.)
	c. Der Rettungsring beobachtete den Knochen stundenlang. (filler sentence) The lifebelt observed the bone for hours (The lifebelt observed the bone for hours.)
NF	a. Tragisch, dass das Haus in der Provence weinen wird. Tragic that the house in the Provence cry will (Tragic that the house in the provence is going to cry.)
	b. Verständlich, dass die verfeindeten Nachbarn einander entsteinen werden. Comprehensible that the antagonized neighbors each other disstone will

Table 4 (continued)

Type	Examples
	(It stands to reason that the antagonized neighbors are going to disstone each other.)
c.	Bald fliegen die Zeltstangen wieder nach Süden. (filler sentence)
	Soon fly the tent poles again to south
	(Soon the tent poles will fly back southward.)

(2130 ms) than for nonsensical (2180 ms) sentences, $F(1, 96) = 56.90$, $MSe = 8643.4$, $p < 0.001$, $\eta^2 = 0.372$. As in Experiment 2, participants produced quicker responses with the right (2152 ms) than with the left (2158 ms) hand, though this effect did not reach statistical significance this time, $F(1, 96) = 1.66$, $MSe = 5189.3$, $p = 0.201$, $\eta^2 = 0.02$. Most crucially, however, there was no indication that the effect of temporal reference was modulated by response hand, $F(1, 96) = 0.19$, $MSe = 4033.4$, $p = 0.668$, $\eta^2 = 0.00$. This lack of an interactive effect is consistent with the results of Experiment 2. A power analysis analogous to the one conducted for Experiment 2 yielded a power of 99.95% for detecting a potential congruency effect with effect size of 0.5.

Furthermore, the interaction between sentence content and temporal reference produced a reliable effect, $F(1, 96) = 61.70$, $MSe = 3090.5$, $p < 0.001$, $\eta^2 = 0.39$. Participants tended to produce longer RTs for past- than for fu-

ture-related nonsensical sentences, but tended to produce the reverse RT pattern for sensible sentences. Neither the interaction of hand and sentence content, $F(1, 96) = 1.78$, $MSe = 57331.5$, $p = 0.186$, $\eta^2 = 0.02$, nor the three-way interaction of all three factors, $F(1, 96) = 1.78$, $MSe = 3196.2$, $p = 0.119$, $\eta^2 = 0.03$, was statistically significant.

An ANOVA on PC produced a main effect of temporal reference, $F(1, 96) = 11.83$, $MSe = 12.0$, $p = 0.001$, $\eta^2 = 0.11$; there were slightly more correct responses for future- than for past-related sentences (95.5 vs. 94.6%). Finally, the interaction of sentence content and temporal reference was statistically reliable, $F(1, 96) = 16.58$, $MSe = 11.0$, $p < 0.001$, $\eta^2 = 0.15$; the effect of temporal reference was larger for nonsensical than for sensible sentences. There was no further statistical significant main or interactions effects on PC due to the factors temporal reference, sentence content, and hand.

In conclusion, the results of Experiment 3 basically parallel those of Experiment 2. Thus, even when temporal information about past or future is moved toward the end of a sentence, the congruency effect observed in Experiment 1 remains absent. This null effect provides once more evidence against the notion that the mental timeline becomes automatically activated during sentence processing and consequently facilitates (hampers) response activation in the congruent (incongruent) condition, even if temporal information is located toward the end of a sentence and thus would temporally overlap with response selection.

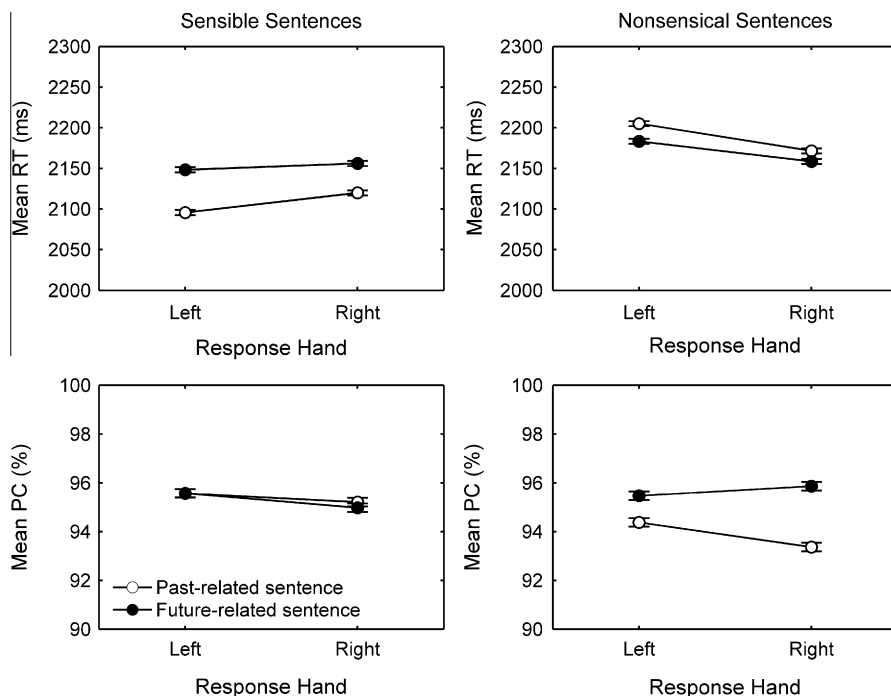


Fig. 3. Mean RT and percentage of correct responses as a function of response hand and temporal reference for Experiment 3, separately for sensible sentences (left panels) and nonsensical sentences (right graphs). The standard error SE of the mean was computed from the mean square error MSe for the interaction of factor response hand and temporal reference as recommended by Loftus and Masson (1994) and Masson and Loftus (2003). Note that this standard error is particularly appropriate for assessing the interaction of these two factors. Each point shows Mean ± 1 SE.

6. General discussion

Recent RT studies (Santiago et al., 2007; Torralbo et al., 2006; Vallesi et al., 2008; Weger & Pratt, 2008) have demonstrated the existence of a mental timeline that runs from the left to the right when people classify single words as past- or future-related in a speeded RT task. Responses are generally faster when the response direction is compatible with the mental timeline than when it is not. The present study had two goals. First it examined whether this mental timeline is also involved when people process complete sentences instead of isolated words. Second, it assessed whether processing sentences would automatically activate the mental timeline, which would provide evidence for the notion that activation of this timeline is functionally involved in the processing of a sentence's content.

In Experiment 1, we combined the experimental paradigms of the Santiago et al. (2007) and Glenberg and Kaschak (2002) studies to address this question. The results of this experiment revealed a clear left–right congruency effect. The fact that response positions are irrelevant to this task of judging the temporal meaning of a sentence suggests that thinking about the sentence's temporal meaning activates spatial response patterns, as one would expect from the metaphoric mapping account (Boroditsky, 2000; Boroditsky & Ramscar, 2002).

Experiment 2 examined two classes of hypotheses about the congruency effect found in Experiment 1. According to the first one, the temporal meaning of a sentence automatically activates a directional spatial code that facilitates the response in the congruent condition (e.g., Mattes, Leuthold, & Ulrich, 2002; Vallesi et al., 2008). We reasoned that if the left–right congruency effect is the signature of automatic response activation, the effect should also emerge in a task in which temporal information is task-irrelevant, similarly to the SNARC effect (Dehaene et al., 1993) or the Simon effect (Kornblum, Hasbroucq, & Osman, 1990). Since the congruency effect disappeared in Experiment 2, this hypothesis received no support.

One might argue, however, that the activation of response codes by temporal information is non-durable and thus had decayed by the time when subjects produced their response after having read the complete sentence (see Taylor & Zwaan, 2008). Experiment 3 was designed to address this issue. To this end, words that carry temporal information about past or future were moved toward the end of a sentence in this experiment. We conjectured that if temporal sentence information produces a transient automatic activation of response codes, an influence of this activation should manifest in RT when this activation temporally overlaps with the selection and execution of a response. Consequently, we expected a left–right congruency effect in this experiment. The data of Experiment 3, however, did not support this hypothesis.

Thus, the data of Experiments 2 and 3 are consistent with a non-automatic account of the congruency effect found in Experiment 1. Following Weger and Pratt (2008), we propose that response selection is more effi-

cient when salient features of the stimulus (e.g., past and future) and the response (e.g., left and right) correspond than when they do not (Proctor & Cho, 2006). In conclusion, the results of Experiments 2 and 3 do not call into question the existence of a mental timeline. The results of Experiments 2 and 3, however, leave us with two mutually exclusive possibilities. According to the first possibility, the mental timeline is not automatically activated by linguistic information and thus not required in the processing of sentence content. According to the second possibility, linguistic information automatically activates the mental timeline; this activation is, however, too weak to manifest itself in RT when temporal information is task-irrelevant. Note that this second possibility is consistent with the notion that activation of the mental time is involved in the processing of linguistic information.

Although the present results cannot unequivocally discriminate between these two possibilities, the second possibility appears less likely to us – if activation of the timeline would be automatic, why should it become manifest only when temporal information is task-relevant? In addition, the ubiquity of the SNARC effect in the RT literature suggests that automatic activation of the mental number line does easily transfer to the level of RT. Therefore, why should automatic activation of the mental timeline not elicit an effect analogous to the SNARC effect, especially if it is assumed that similar cortical metrics underlie these kinds of phenomena (Walsh, 2003)?²

In agreement with the idea of such a non-automatic account, the obtained additive effects of response hand and temporal content on mean RT in Experiments 2 and 3 fit well with the results reported by Santiago et al. (2007). These authors did not only manipulate the time–space mapping but also the spatial location of their stimulus material on the screen. A time-related target word appeared either to the left of the fixation point or to the right, although screen position was a task-irrelevant dimension. Screen position did not significantly modulate the left–right time congruency effect on RT, suggesting that the effect is not of the Simon-type and thus not automatic.

Weger and Pratt (2008) reached a similar conclusion. In two additional experiments, they presented either a prospective word (e.g., *later*) or a retrospective word (e.g., *past*) in the middle of the screen. Briefly after this word,

² One reviewer of this article suggested that a left-to-right scanning of the sentences may account for the congruency effect observed in Experiment 1. This reviewer conjectured that such a scanning process may activate the spatial left-to-right dimension and thus facilitate the interaction between spatial and temporal dimensions. We have (Ulrich et al., in preparation) recently conducted additional experiments that required push/pull movements within the sagittal plane rather than left/right responses within the horizontal plane as in Experiment 1. In the congruent condition, subjects were asked to push/pull a handle in response to a SF/SP sentence and in the incongruent condition, the S–R mapping of these push/pull responses was reversed. Consistent with the idea that the future is mentally represented in front of us whereas the past behind us (e.g., Boroditsky, 2000, Núñez & Sweetser, 2006), faster responses were obtained in the congruent condition. Therefore, this result argues against the notion that such a left-to-right scanning process is the sole cause of the time by space congruency effect observed in our experiments. In addition, this account cannot explain why this effect is absent in Experiments 2 and 3.

an unpredictable visual target appeared either to the left or to the right of the word with equal probability and required a speeded response with the left or right hand, respectively. Although the temporal content of the word was uncorrelated with response side, faster responses occurred when left-side (right-side) targets followed retrospective (prospective) words than when the target positions were reversed. By contrast, this word-target effect disappeared in a simple RT task, when subjects pressed a single key as soon as they had detected a target on either side. Although one might be tempted to assume that this specific pattern of results shows automatic response code activation at the level of response selection, Weger and Pratt argue against this interpretation, because the effect was susceptible to semantic saturation, in which repetition of the same material eliminates the effect of meaning (Smith & Klein, 1990). Therefore, Weger and Pratt prefer a non-automatic account, similar to the one that was suggested in the previous paragraphs.

Recently, Quillet, Santiago, Funes, and Lupiáñez (2010) provided evidence that the temporal reference of isolated words can prime spatial attention and motor responses. In a modified spatial cuing paradigm, participants memorized a word's temporal reference while they performed a speeded visual location task or a spatial Stroop task. For example, in their first experiment, participants memorized a past- or future-related word while they performed a speeded RT task, in which a target was presented either to the left or right side on a computer monitor. Responses were faster for left-side (right-side) targets when the memorized word was related to the past (future) than for the reversed combinations of temporal reference and spatial location. These results show that mere activation of temporal concept orients spatial attention to the left for past-related expressions and to the right for future-related expressions.

In conclusion, this study demonstrated a clear time-space congruency during online processing of a sentence. This effect is consistent with and further corroborates RT studies (Santiago et al., 2007; Torralbo et al., 2006; Weger & Pratt, 2008) that have found such congruency effects with various types of isolated words. These results are consistent with the metaphoric mapping theory: Abstract concepts, such as time, are represented in terms of more concrete concepts. The data, however, may also help to constrain this theory in at least two respects and thus help to further advance it. First, findings concerning the linguistic relevance of a mental time line running from left to right provide experimental support for the assumption that the mapping from space to time takes place at the conceptual level rather than at the level of linguistic expressions, given that no language has been attested that has temporal expressions corresponding to the notions of left and right. Secondly, the present results of Experiments 2 and 3 do not support the notion that the time-space congruency effect obtained in Experiment 1 is the signature of an automatic process as a strong version of the metaphoric mapping theory might suggest. Although available data do not clearly support automatic activation of the mental timeline, a definite answer to this question must await future research.

Acknowledgements

We thank Simone Alex, Rebecca-Sarah Erschens and Andy Kramer for their assistance in data collection, Barbara Kaup, Jeff Miller, and Tanja Seifried for constructive comments and advice, and Claudia Kühner for her help in data analysis. The critical comments of three anonymous reviewers are highly appreciated. This work was supported by the Deutsche Forschungsgemeinschaft (SFB 833 project B7 Ulrich/Maienborn and UL 116/10-1).

References

- Anderson, J. R. (1983). *The architecture of cognition*. Cambridge, MA: Harvard University Press.
- Barsalou, L. W. (2008). Grounded cognition. *Annual Review of Psychology*, 59, 617–645.
- Boroditsky, L. (2000). Metaphoric structuring: Understanding time through spatial metaphors. *Cognition*, 75, 1–28.
- Boroditsky, L. (2001). Does language shape thought? Mandarin and English speakers' conceptions of time. *Cognitive Psychology*, 43, 1–22.
- Boroditsky, L., & Ramscar, M. (2002). The roles of body and mind in abstract thought. *Psychological Science*, 13, 185–189.
- Brainard, D. H. (1997). The psychophysics toolbox. *Spatial Vision*, 10, 433–436.
- Casasanto, D., & Boroditsky, L. (2008). Time in the mind: Using space to think about time. *Cognition*, 106, 579–593.
- Casasanto, D., Fotakopoulou, O., & Boroditsky, L. (2010). Space and time in the child's mind: Evidence for a cross-dimensional asymmetry. *Cognitive Science*, 34, 387–405.
- Chatterjee, A. (2001). Language and space: Some interactions. *Trends in Cognitive Sciences*, 5, 55–61.
- Clark, H. H. (1973). Space, time, semantics, and the child. In T. E. Moore (Ed.), *Cognitive development and the acquisition of language* (pp. 27–64). New York: Academic Press.
- Dehaene, S., Bossini, S., & Giraux, P. (1993). The mental representation of parity and number magnitude. *Journal of Experimental Psychology: General*, 122, 371–396.
- Evans, V. (2004). *The structure of time: Language, meaning and temporal cognition*. Amsterdam: John Benjamins.
- Gentner, D., Imai, M., & Boroditsky, L. (2002). As time goes by: Evidence for two systems in processing space → time metaphors. *Language and Cognitive Processes*, 17, 537–565.
- Gevers, W., Reynvoet, B., & Fias, W. (2003). The mental representation of ordinal sequences is spatially organized. *Cognition*, 87, B87–B95.
- Gevers, W., Reynvoet, B., & Fias, W. (2004). The mental representation of ordinal sequences is spatially organized: Evidence from days of the week. *Cortex*, 40, 171–172.
- Glenberg, A. M., & Kaschak, M. (2002). Grounding language in action. *Psychonomic Bulletin & Review*, 9, 558–565.
- Grondin, S. (2001). From physical time to the first and second moments of psychological time. *Psychological Bulletin*, 127, 22–44.
- Harnad, S. (1990). The symbol grounding problem. *Physica*, 42, 335–346.
- Haspelmath, M. (1997). *From space to time: Temporal adverbials in the world's languages*. München: Lincom Europa.
- Hommel, B., & Prinz, W. (Eds.). (1997). *Theoretical issues in stimulus-response compatibility*. Amsterdam: North-Holland.
- Hubbard, E. M., Piazza, M., Pinel, P., & Dehaene, S. (2005). Interactions between number and space in parietal cortex. *Nature Review Neuroscience*, 6, 435–448.
- Klein, W. (2009). Concepts of time. In W. Klein & P. Li (Eds.), *The expression of time* (pp. 5–38). Berlin: Mouton de Gruyter.
- Kornblum, S., Hasbroucq, T., & Osman, A. (1990). Dimensional overlap: Cognitive basis for stimulus-response compatibility: A model and taxonomy. *Psychological Review*, 97, 253–270.
- Lakoff, G., & Johnson, M. (1980). *Metaphors we live by*. Chicago: University of Chicago Press.
- Le Poidevin, R. (2004). A puzzle concerning time perception. *Synthese*, 142, 109–142.
- Loftus, G. R., & Masson, M. E. J. (1994). Using confidence intervals in within-subjects designs. *Psychonomic Bulletin & Review*, 1, 476–490.
- Masson, M. E. J., & Loftus, G. R. (2003). Using confidence intervals for graphically based data interpretation. *Canadian Journal of Experimental Psychology*, 57, 203–220.

- Mattes, S., & Ulrich, R. (1998). Directed attention prolongs the perceived duration of a brief stimulus. *Perception & Psychophysics*, *60*, 1305–1317.
- Mattes, S., Leuthold, H., & Ulrich, R. (2002). Stimulus–response compatibility in intensity–force relations. *Quarterly Journal of Experimental Psychology Section A – Human Experimental Psychology*, *55*, 1175–1191.
- Mayr, S., Erdfelder, E., Buchner, A., & Faul, F. (2007). A short tutorial of GPower. *Tutorials in Quantitative Methods for Psychology*, *3*, 51–59.
- Mo, S. S., & Michalski, V. A. (1972). Judgment of temporal duration of area as a function of stimulus configuration. *Psychonomic Science*, *27*, 97–98.
- Miller, J. (2009). What is the probability of replicating a statistically significant effect? *Psychonomic Bulletin & Review*, *16*, 617–640.
- Newell, A. (1990). *Unified theories of cognition*. Cambridge, MA: Harvard University Press.
- Núñez, R. E., & Sweetser, E. (2006). With the future behind them: Convergent evidence from Aymara language and gesture in the crosslinguistic comparison of spatial construals of time. *Cognitive Science*, *30*, 401–450.
- Ono, F., & Kawahara, J. I. (2007). The subjective size of visual stimuli affects the perceived duration of their presentation. *Perception & Psychophysics*, *69*, 952–957.
- Pelli, D. G. (1997). The videotoolbox software for visual psychophysics: Transforming numbers into movies. *Spatial Vision*, *10*, 437–442.
- Price, M. C., & Mentzoni, R. A. (2008). Where is January? The month–SNARC effect in sequence–form synaesthetes. *Cortex*, *44*, 890–907.
- Proctor, R. W., & Cho, Y. S. (2006). Polarity correspondence: A general principle for performance of speeded binary classification tasks. *Psychological Bulletin*, *132*, 416–442.
- Radden, G. (2004). The metaphor TIME AS SPACE across languages. In N. Baumgarten, C. Böttger, M. Motz, & J. Probst (Eds.), *Übersetzen, Interkulturelle Kommunikation, Spracherwerb und Sprachvermittlung – das Leben mit mehreren Sprachen: Festschrift für Juliane House zum 60. Geburtstag* (pp. 225–239). Bochum: Aks-Verlag.
- Raaijmakers, J. G. W., Schrijnemakers, J. M. C., & Gremmen, F. (1999). How to deal with “The language-as-fixed-effect fallacy”: Common misconceptions and alternative solutions. *Journal of Memory and Language*, *41*, 416–426.
- Raaijmakers, J. G. W. (2003). A further look at the “language-as-fixed-effect fallacy”. *Canadian Journal of Experimental Psychology*, *57*, 141–151.
- Raposo, A., Moss, H. E., Stamatakis, E. A., & Tyler, L. K. (2009). Modulation of motor and premotor cortices by actions, action words and action sentences. *Neuropsychologia*, *47*, 388–396.
- Roeckelein, J. E. (2000). *The concept of time in psychology: A resourcebook and annotated bibliography*. Westport, CT: Greenwood Press.
- Santiago, J., Lupiáñez, J., Pérez, E., & Funes, M. J. (2007). Time (also) flies from left to right. *Psychonomic Bulletin & Review*, *14*, 512–516.
- Santiago, J., Román, A., Ouellet, M., Rodríguez, N., & Pérez-Azor, P. (2010). In hindsight, life flows from left to right. *Psychological Research*, *74*, 59–70.
- Quellet, M., Santiago, J., Funes, M. J., & Lupiáñez, J. (2010). Thinking about the future moves attention to the right. *Journal of Experimental Psychology: Human Perception and Performance*, *36*, 17–24.
- Simon, J. R., & Rudell, A. P. (1967). Auditory S–R compatibility: The effect of an irrelevant cue on information processing. *Journal of Applied Psychology*, *51*, 300–304.
- Smith, L., & Klein, R. (1990). Evidence for semantic satiation: Repeating a category slows subsequent semantic processing. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *16*, 852–861.
- Taylor, L. J., & Zwaan, R. A. (2008). Motor resonance and linguistic focus. *Quarterly Journal of Experimental Psychology*, *61*, 896–904.
- Torrallbo, A., Santiago, J., & Lupiáñez, J. (2006). Flexible conceptual projection of time onto spatial frames of reference. *Cognitive Science*, *30*, 745–757.
- Tversky, B., Kugelmass, S., & Winter, A. (1991). Cross-cultural and developmental trends in graphic productions. *Cognitive Psychology*, *23*, 515–557.
- Umiltà, C., & Nicoletti, R. (1990). Spatial S–R compatibility. In R. W. Proctor & T. G. Reeve (Eds.), *Stimulus–response compatibility: An integrated perspective* (pp. 98–116). Amsterdam: North-Holland.
- Vallesi, A., Binns, M. A., & Shallice, T. (2008). An effect of spatial–temporal association of response codes: Understanding the cognitive representations of time. *Cognition*, *107*, 501–527.
- Walsh, V. (2003). A theory of magnitude: Common cortical metrics of time, space and quantity. *Trends in Cognitive Sciences*, *7*, 483–488.
- Weger, U. W., & Pratt, J. (2008). Time flies like an arrow: Space–time compatibility effects suggest the use of a mental timeline. *Psychonomic Bulletin & Review*, *15*, 426–430.
- Whitrow, Geoffrey, J. (1980). *The natural philosophy of time*. Oxford: Clarendon Press.
- Woodrow, H. (1951). Time perception. In S. S. Stevens (Ed.), *Handbook of experimental psychology* (pp. 1224–1236). New York: John Wiley & Sons.
- Xuan, B., Zhang, D., He, S., & Chen, X. (2007). Larger stimuli are judged to last longer. *Journal of Vision*, *7*, 1–5.