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Do we map remembrances to the left/back and expectations to the right/front of a mental timeline? Space–time congruency effects with retrospective and prospective verbs

Claudia Maienborn [a,*], Simone Alex-Ruf [a], Verena Eikmeier [b], Rolf Ulrich [b]

[a] German Department, University of Tübingen, Wilhelmstr. 50, 72074 Tübingen, Germany
[b] Department of Psychology, University of Tübingen, Schleichstr. 4, 72076 Tübingen, Germany

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ABSTRACT

Recent experimental studies have shown that people code time in terms of a mental timeline which typically runs from left to right or from back to front. Determining the cognitive function of this mental timeline for language processing, however, is still an unsettled issue. Whereas the studies of Ulrich and Maienborn (2010) and Ulrich et al. (2012) argue against an automatic activation of the mental timeline for the interpretation of tense and temporal adverbials at sentence level, Sell and Kaschak (2011) observe an automatic activation for the processing of past- and future-related sentences in small stories. The present paper reports the results of three experiments which examine the processing of sentences with retrospective and prospective verbs (e.g., *to remember*, *to regret* vs. *to expect*, *to announce*) in present tense, which locate a second, embedded event in the past or the future. When temporal information was task-relevant, a space–time congruency effect emerged (Experiment 1). This suggests that the mental timeline is not only linked to overtly deictic linguistic material but may also be construed in a more intricate way through the compositional construction of sentence meaning. The congruency effect disappeared, however, when temporal information was task-irrelevant (Experiments 2 and 3), suggesting that the mental timeline is not functionally involved in the cognitive processing of these especially demanding two-event sentences. The results of the present study support the conclusion that the relevant factor driving an automatic activation of the mental timeline is not the number of linguistically expressed events, but might rather be the number of sentential units.

1. Introduction

Time is an essential component of our cognition. Time structures our thoughts and enables us to understand the changes in the external world that we perceive. All natural languages have rich means to talk about time and to express different kinds of temporal configurations (e.g., Haspelmath, 1997; Klein, 2009). Although being so fundamental to language and cognition, time is nevertheless an abstract concept. There appears to be no basic physical stimulus of time and hence we have no immediate experiential access to time comparable to, e.g., the experience of a visual object (e.g., Eikmeier, Alex-Ruf, Maienborn, Schröter, & Ulrich, 2014; Evans, 2006). This raises the question of the cognitive grounding of our notion of time. How do we construe the concept of time? This question has attracted the attention of philosophers, linguists and cognitive psychologists alike already for a long time. The common conception among these disciplines is that the abstract notion of time is conceptualized through an analogical extension from the more concrete, experientially accessible domain of space. Núñez and Cooperrider (2013) call this the "spatial construal of time". Our common understanding of time as a one-dimensional, unidirectional, dense flow is thus derived from our richer conception of the three-dimensional space according to this view. Many findings concerning time in language and cognition lend support to this view (e.g., Boroditsky, 2000; Boroditsky & Ramscar, 2002; Casasanto & Boroditsky, 2008; Clark, 1973; Eikmeier, Schröter, Maienborn, Alex-Ruf, & Ulrich, 2013; Evans, 2006; Haspelmath, 1997; Moore, 2006; Traugott, 1975). Yet, beyond this general assumption, many details of such a mapping from space to time, its implementation, its scope and its implications for the representation and processing of temporal information still remain unresolved.

An area of investigation in which some of these issues have recently been studied experimentally is the conception of deictic time in terms of a mental timeline that typically runs along the transversal axis from left to right or along the sagittal axis from back to front (see Eikmeier et al., 2014, for an overview). The deictic center of this mental timeline marks the present. The past is mapped to the left/back on this mental timeline, and the future is mapped to the right/front. Note that some deviations from these standard orientations of the mental timeline have been attested in the literature. For instance, Núñez and Sweetser

* Corresponding author. Tel.: +49 7071 29 78445.
E-mail address: claudia.maienborn@uni-tuebingen.de (C. Maienborn).

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(2006) present the case of Aymara, an Amerindian language, which appears to support a mapping of the past to the front and of the future to the back. Furthermore, several studies have established the influence of the predominant reading and writing direction on the orientation of the mental timeline (e.g., Bergen & Lau, 2012; Fuhrman & Boroditsky, 2010; Maas & Russo, 2003; Ouellet, Santiago, Funes, & Lupiáñez, 2010). Taken together these studies suggest that when thinking about deictic time we make use of a mental timeline, which is not hard-wired but may run along both the transversal and the sagittal axis and whose orientation is culturally determined (see also Santiago, Román, & Ouellet, 2011, for the flexibility in the orientation of the mental timeline).[1]

But what is the cognitive function of such a mental timeline? More specifically, what role does it play in language processing? Several reaction time studies revealed the signature of the mental timeline during the processing of temporal expressions in terms of a space–time congruency effect (e.g., Santiago et al., 2007; Torralbo et al., 2006; Ulrich & Maienborn, 2010). For instance, Santiago et al. (2007) presented the participants words that were related either to the past or to the future such as Spanish *pasado* ('past')/*futuro* ('future'), *ayer* ('yesterday')/ *mañana* ('tomorrow') or *preguntó* ('(he) asked')/*preguntará* ('(he) will ask'). Participants were asked to make a speeded manual response to the temporal content of the word (i.e. past vs. future). In the congruent condition, they were asked to respond with a left-hand keypress to past-related words and with a right-hand keypress to future-related words. This assignment was reversed in the incongruent condition. Shorter reaction times were observed in the congruent than in the incongruent condition supporting the notion of a mental timeline running from left to right.

Ulrich and Maienborn (2010) continued this line of research by investigating whether the space–time congruency effect observed by Santiago et al. (2007) and Torralbo et al. (2006) for isolated words generalizes to the processing of complete sentences. In their first experiment, participants were presented sentences that referred either to the past (e.g., German *Mona und Diana tanzten die ganze Nacht* 'Mona and Diana danced the whole night through') or to the future (e.g., *Wir werden in fünf Minuten in Bonn aussteigen* 'We will get off in Bonn in five minutes'). In the congruent condition, participants responded with a left-hand (right-hand) keypress to sentences referring to the past (future). In the incongruent condition, this assignment was reversed. To make sure that the participants processed the sentence content, nonsensical sentences (e.g., *Die Tannen haben sich badend ihren Mantel angezogen* 'The fir trees have put on their coat while bathing') were presented in catch trials (see Glenberg & Kaschak, 2002), and the participants were asked to refrain from responding in this case (i.e., sensicality judgment). Consistent with the results of Santiago et al. (2007) and Torralbo et al. (2006) reaction time was shorter for the left–past/right–future mapping than for the left–future/right–past mapping. This space–time congruency effect confirms the psychological reality of a left-to-right mental timeline also for the processing of whole sentences.

[1] It must be stressed that the notion of a "mental timeline" is not meant to be taken literally. It simply holds that in Western cultures the past is associated with the left and the future with the right. Therefore, the notion of a mental timeline as used here and in the literature would also be consistent with a polarity coding account (Gevers et al., 2010; Proctor & Cho, 2006; Ulrich & Maienborn, 2010). According to this account, opposite concepts like "past" and "future" or "left" and "right" constitute a single category. Each single concept is linked with either a positive or a negative pole. According to this account, "past" and "left" would be associated with a negative pole and "future" and "right" with a positive pole. Thus if, e.g., a reaction time task requires a left (right) response for a past (future)-related sentence, the processing of time-related linguistic information is facilitated if the concepts of the two categories refer to the same poles ("past" and "left" to the negative pole and "future" and "right" to the positive pole). Evidence in favor of this polarity account has been reported by Gevers et al. (2010) and by Santens and Gevers (2008) with regard to number–space interactions.

The second experiment of Ulrich and Maienborn (2010) aimed at exploring further the linguistic relevance of the mental timeline by testing whether the mental timeline is necessarily involved when processing temporal sentence information and thus automatically activated (automatization hypothesis). In this case the space–time congruency effect should show up even if the temporal dimension is task-irrelevant. This is expected in analogy to the SNARC effect (Dehaene, Bossini, & Giraux, 1993) and the Simon effect (Simon & Rudell, 1967), which both demonstrate that automatically activated task-irrelevant information influences the speed of a response. Therefore, the second experiment of Ulrich and Maienborn employed a sensicality judgment task instead of the temporal judgment task. In each trial participants were asked to judge the content of a past- or future-related sentence (i.e., sensible vs. nonsensical) with a left or right keypress. Thus, the temporal information of the sentence was no longer task-relevant. Yet, if the mental timeline were automatically activated in the course of sentence understanding, it should be easier for participants to classify past-related sentences as sensible when they have to press the left key rather than the right key. Analogously, processing of future-related sentences should facilitate a right-hand keypress response (see, e.g., Glenberg & Kaschak, 2002; Lachmair, Dudschig, De Filippis, de la Vega, & Kaup, 2011, for such automatic response activations triggered by task-irrelevant spatial word and sentence information). Yet, contrary to the automatization hypothesis, no space–time congruency effect was observed for the sensicality judgment task. Ulrich and Maienborn have taken this result to argue against an automatic activation of the mental timeline.

In summary, then, the results by Ulrich and Maienborn (2010) indicate that the space–time congruency effect emerges when temporal sentence information is task-relevant but not when this information is task-irrelevant. They have concluded that the space–time congruency effect on the transversal axis observed in previous studies reflects a facilitated memory access instead of automatic sensorimotor activation. According to this memory hypothesis the spatial locations of left and right are associated with past and future, respectively. Participants use these locations as memory cues for performing the RT task. Because the congruent stimulus–response mapping is easier to remember and thus easier to retrieve during the RT task, responses are faster when the mapping is congruent than when it is incongruent. This memory hypothesis implies that the space–time congruency effect only emerges when the RT task demands a mapping of time to specific locations in space.

The results of Ulrich and Maienborn (2010) could be generalized also to the back–front mental timeline (Ulrich et al., 2012). With respect to the question of the linguistic relevance of the mental timeline, these findings suggest that the mental timeline is not functionally involved in the processing of temporal sentence information. They hint toward the assumption that the mental timeline could rather be an epiphenomenon without a genuine linguistic purpose — at least as far as the composition of sentence meaning at the level of grammar is concerned.

The results of Ulrich and Maienborn (2010) and Ulrich et al. (2012) appear to be at variance with the experimental results of Sell and Kaschak (2011), which provide evidence for an automatic activation of the mental timeline. Crucially, though, the study of Sell and Kaschak tested the automatization hypothesis for small texts that involved more than one event. Furthermore, an automatic space–time congruency effect was only observed for sufficiently large time shifts. More specifically, Sell and Kaschak presented their participants texts consisting of three sentences, such as in the following example (1)–(3). The second sentence of these stories expressed a time shift either to the past or to the future (see (2a) vs. (2b)).

(1) Jackie is taking a painting class.
(2) a. Last month, she learned about paintbrushes.
b. Next month, she will learn about paintbrushes.
(3) It is important to learn paintbrush techniques.

Participants made sensicality judgments about each sentence by moving their right hand either away from or toward their body. Although the temporal content of the critical second sentence was not task-relevant, this information nevertheless interacted with movement direction. That is, reaction time was shorter when sentences expressing past events were mapped on responses toward the body and sentences expressing future events were mapped on responses away from the body. This space–time congruency effect disappeared, however, when the time shift in (2) was small (i.e. *last month*/*next month* vs. *yesterday*/*tomorrow*) and when the responses were spatially arranged instead of response movements (i.e., one response hand located close to the body and the other one located farther away from the body). Sell and Kaschak have speculated that only a large temporal break in the ongoing events requires a major update of the comprehension model and thus leads to a spatial ordering of the expressed events on the mental timeline.

How can the diverging results of Ulrich and Maienborn (2010), Ulrich et al. (2012) and Sell and Kaschak (2011) concerning the automatic activation of the mental timeline be reconciled? And what conclusions can be drawn for the linguistic relevance and scope of the mental timeline? A possible explanation could be that the mental timeline is activated automatically not at sentence level but at discourse level, when several narrated events must be integrated into a coherent discourse structure. That is, it may be the case that spatial concepts are only activated when participants build up a discourse model, e.g., by ordering the narrated events along the mental timeline. By contrast, comprehending the genuinely grammatically determined content of a simple sentence, which typically expresses a single event, may not necessitate the activation of spatial concepts in order to process the given temporal information. To be more precise, this line of argumentation hints at two possible sources for an automatic activation of the mental timeline. The relevant factor could be either the number of events that are to be temporally related, or the number of sentences. Typically, a simple sentence talks about a single event. But simple sentences may also express two events ordered along the mental timeline.

The aim of the present study is to shed more light on this issue. Specifically, the study has two goals. First, it aims at extending our knowledge on the kind of linguistic expressions which are apt to activate the mental timeline. And, secondly, it aims at testing the hypothesis of an automatic activation of the mental timeline in a sentential context which involves two separate, sequentially ordered events.

As for the first goal, previous studies have established that the mental timeline may be triggered by core deictic expressions such as tense (past vs. future) and temporal adverbials (e.g., *yesterday* vs. *tomorrow*). It is an unsettled issue whether the observed space–time congruency effects can only be observed for overtly deictic expressions or whether they also emerge when reference to the past or future is established in a more indirect way, which requires more thorough linguistic processing. Particularly, we will investigate whether retrospective verbs (e.g., *to remember*, *to regret*, *to reconstruct*, *to correct*) and prospective verbs (e.g., *to expect*, *to announce*, *to predict*, *to fear*) also evoke activation of the mental timeline. When used in present tense, these verbs typically presuppose an additional event (expressed by an internal argument of the verb) that is located in the past or the future, respectively (see the illustrations from German in (4) and (5)).

(4) a. Der Zeuge erinnert sich an den Pistolenschuss.
'The witness remembers the pistol-shot.'
b. Peter bereut seine voreilige Abreise.
'Peter regrets his hasty departure.'
c. Der Kommissar rekonstruiert den Banküberfall.
'The inspector reconstructs the bank robbery.'
d. Der Dozent berichtigt seine Aussage.
'The lecturer corrects his statement.'
(5) a. Der Patient erwartet einen schmerzfreien Eingriff.
'The patient expects a painless operation.'
b. Der Professor kündigt den Gastvortrag an.
'The professor announces the guest lecture.'
c. Der Bergführer prophezeit schlechtes Wetter.
'The mountain guide predicts bad weather.'
d. Stefan fürchtet sich vor der mündlichen Prüfung.
'Stefan is afraid of the oral exam.'

None of the expressions in the sentences in (4) and (5) refers to the past or the future by its own. That is, neither the grammatical tense, nor the event nominals in isolation, nor the lexical semantics of the verbs establish past or future reference. First, all sentences are realized in present tense. Moreover, eventive nouns such as *Pistolenschuss* ('pistol-shot'), *Abreise* ('departure'), *Gastvortrag* ('guest lecture') do not involve either past or future reference. And, finally, the retrospective and prospective verbs only express an anteriority or posteriority relation between the main event and the embedded event argument but they do not locate the embedded event in the past or the future. A sentence such as (6), e.g., which is the past tense version of (5b), does not allow us to infer that the guest lecture will take place in the future. The lecture may already have taken place in the past. The sentence only expresses posteriority, i.e. the guest lecture takes place after the professor's announcement.

(6) Der Professor kündigte den Gastvortrag an.
'The professor announces the guest lecture.'

In the same vein, there is no inference to the past in (7a) nor to the future in (7b). In (7a), past reference is blocked by the temporal attribute *morgige* (adjectival form of 'tomorrow').[2] And in (7b), the thunder storm is rather located in the present due to the deictic locative adverb *draußen* ('outside').

(7) a. Der Professor erinnert sich an den morgigen Gastvortrag.
'The professor recalls the guest lecture tomorrow.'
b. Stefan fürchtet sich vor dem Gewitter draußen.
'Stefan is afraid of the thunder storm outside.'

In sum then, the discussion of the above data shows that there is no explicitly coded link to the past or future in sentences of type (4) and (5). It is only the combination of these elements — present tense, retrospective/prospective verb and event nominal — that establishes the reference to the past or the future of the embedded event in the course of sentence composition. Thus, reference to past or future cannot simply be read off from an explicit lexical or grammatical element, as it was the case in previous studies. Rather, to relate sentences such as (4) and (5) to the past or future requires a more thorough processing and assembling of different pieces of temporal information that are distributed over the whole sentence. Experiment 1 was designed to test whether the mental timeline is also activated under these linguistically more intricate circumstances when temporal information is task-relevant.

As for the second goal, sentences with retrospective and prospective verbs following the pattern of (4) and (5) provide an interesting test case for the automatization hypothesis for two reasons. First, given that these sentences require a more thorough processing to determine the temporal location of the embedded event, meaning composition might benefit from an automatic activation of the mental timeline for this especially demanding case. Secondly, although being simple sentences they introduce two separate events and bring them into a temporal order. That is, Experiments 2 and 3 test whether the sentence-internal expression of two events in terms of a retrospective/prospective verb that locates a second event either in the past or future

[2] Note that the German verb *erinnern* subsumes both 'to remember' and 'to recall'.

suffices to activate the mental timeline automatically, i.e., when temporal information is task-irrelevant. While Experiment 2 uses a left-to-right orientation of the mental timeline, Experiment 3 adopts a back-to-front orientation. In sum, the three experiments aim at establishing a further possible linguistic trigger for the mental timeline, and they strive for a better understanding of its linguistic functionality by testing the automatic activation at the level of sentential meaning composition for sentences which express the temporal ordering of two events.

2. Experiment 1

Experiment 1 examined whether participants can classify the temporal reference of a sentence with a retrospective/prospective verb faster when the response assignment is congruent with the left-to-right orientation of a mental timeline. This experiment is construed along the lines of Experiment 1 from Ulrich and Maienborn (2010). In each trial of the experiment, a sentence with a retrospective or prospective verb in present tense that embeds a second event expression (see the examples in (4) and (5) above) was presented to a participant on a computer screen. In the congruent condition, the participant responded with a left-hand keypress to sentences in which the embedded event expression refers to the past via a retrospective verb and with a right-hand keypress to sentences in which the embedded event expression refers to the future via a prospective verb. In the incongruent condition, this assignment was reversed. To assure that participants process the content of a sentence, nonsensical sentences were presented in half of the trials and participants were to refrain from responding in this case. Nonsensical sentences also involved present tense retrospective and prospective verbs. Some illustrations for nonsensical sentences are given in (8).

(8) a. Der Lehrer erinnert sich an haarigen Beton.
'The teacher remembers hairy concrete.'
b. Frau Müller vergibt dem Feldweg den Einbruch.
'Mrs. Müller forgives the dirt road for the burglary.'
c. Der Schlosser kündigt die schnelle Pfütze an.
'The locksmith announces the fast puddle.'
d. Der Metzger prophezeit fliegende Waschlappen.
'The butcher predicts flying washcloths.'

If the space–time compatibility effect reported by Torralbo et al. (2006), Santiago et al. (2007) and Ulrich and Maienborn (2010) generalizes to the processing of also indirectly supplied, implicit deictic sentence information, response time 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

63 volunteers participated in this 20-min experiment for a payment of 5 €. All were native speakers of German and naive with respect to the experimental hypothesis. 11 participants were excluded from the data analysis because their performance was below the criterion of 90% correct responses. The mean age of the remaining 52 volunteers (34 female and 18 male) was 22.0 years ($SD = 2.2$ years). Seven of these participants reported being left-handed.

2.1.2. Apparatus

The experiment was programmed in E-Prime 2.0 Professional and was run in a sound-attenuated room. Sentences were presented in black against a white background in the middle of a computer screen using 12 point Courier New font. As response tool we used two custom-made key boxes that were placed on the left and right side of a desk in front of the participant.

2.1.3. Stimuli

The stimulus material consisted of 40 sensible sentences and 40 nonsensical sentences. All sentences used present tense. Half of the sensible sentences contained a retrospective verb which located an embedded event (expressed by the verb's internal argument) in the past (S-RETRO; see (4)) and the other half contained a prospective verb which located the embedded event in the future (S-PRO; see (5)). The same set of retrospective and prospective verbs was used for the construction of nonsensical sentences. Half of them contained a retrospective verb (N-RETRO; see (8a, b)), and the other half contained a prospective verb (N-PRO; see (8c, d)). In constructing the sentences, we made every effort to equalize the mean number of syllables per sentence, the mean number of total ASCII characters (including blanks) per sentence, and the mean number of words per sentence across the four sets of sentences (see Table 1).

Furthermore, we conducted two rating studies before the main experiment in order to assemble the sentence material. 52 sensible sentences were rated with respect to their relation to the past or future in a questionnaire study with 11 participants. The participants were asked to make their decision on a five-point-scale running from 1 (meaning 'definitely past') to 5 (meaning 'definitely future'). The mean for past sentences was 1.5 ($SD = 0.4$) and for future sentences 4.7 ($SD = 0.2$). Moreover, 52 sensible and 52 nonsensical sentences were rated by another group of 11 participants with respect to their content based on a rating scale running from 1 (='nonsensical') to 5 (='sensible'). The mean for nonsensical sentences was 1.3 ($SD = 0.4$) and for sensible sentences 4.9 ($SD = 0.2$). Based on the ratings, we selected 40 sensible sentences (20 future-related and 20 past-related sentences) and 40 nonsensical sentences. The non-selected sentences were employed as practice items in Experiments 1–3.

2.1.4. Procedure

Participants were given written information about the task and the stimulus–response mappings. Specifically, participants were instructed to carefully read the sentences presented in each trial and to classify whether the information in the sentences contained a reference to the future or to the past. They responded with one hand when the sentence was future-related and with the other hand if it was past-related. In addition, the instructions emphasized that the response should be performed as quickly and accurately as possible. Half of the participants started with the congruent condition, i.e. they had to press the right key if a sentence referred to the future and the left key if a sentence referred to the past. This mapping was switched to the incongruent condition (future-left, past-right) half-way through the experimental session. The other half proceeded in the reversed order. To avoid that a participant read the same sentence several times during the experiment, the stimulus material was divided into two balanced lists containing 20 sensible and 20 nonsensical sentences each (list A and list B). Each participant read one list in the congruent condition and the other list in the incongruent condition. Thus there were four groups of participants, group 1 began with list A in the congruent condition and switched to list B in the incongruent condition in the middle of the experimental session, the other three groups proceeded as follows: Group 2: list A (incongruent)–list B (congruent); group 3: list B (congruent)–list A (incongruent); group 4: list B (incongruent)–list A (congruent). No sentence appeared twice, i.e. the number of trials in one session was 80. Each block started with 11 practice trials. Only the first 6 practice trials included visual feedback in order to make the transition to the main experiment less obvious, because no feedback was provided afterwards.

A single trial started with the presentation of the fixation cross in the middle of the screen for 250 ms, followed by a blank screen for 500 ms. Then with equal probability either a sensible or a nonsensical sentence appeared for a maximum of 6 s. If the sentence was sensible, participants had to respond within this period of 6 s by pressing the left or the right key. The response of the participant terminated the presentation of the sentence and after 1 s the next trial began. In case of a

Table 1
Sentence statistics (mean ± standard error of mean) for the sentence material used in Experiments 1–3.

	Type of sentence					
	S-RETRO	S-PRO		N-RETRO	N-PRO	
Syllables per sentence	12.2 ± 0.2	12.0 ± 0.2	$t(19) = 1.00$ $p = .330$	12.4 ± 0.2	12.0 ± 0.2	$t(19) = 1.83$ $p = .083$
Characters per sentence	42.8 ± 1.0	43.3 ± 0.8	$t(19) = 0.40$ $p = .695$	44.2 ± 0.9	43.1 ± 0.8	$t(19) = 0.80$ $p = .446$
Words per sentence	5.8 ± 0.2	6.2 ± 0.2	$t(19) = 1.16$ $p = .260$	5.9 ± 0.3	5.8 ± 0.3	$t(19) = 0.47$ $p = .643$

Note. The 4th column provides the t-tests for comparing the means concerning S-RETRO vs. S-PRO, whereas the last column contains the t-tests for comparing the means concerning N-RETRO vs. N-PRO.

nonsensical sentence, participants were to refrain from responding and the sentence disappeared after 6 s (nogo-trial).

2.2. Results and discussion

Separate Analyses of Variance (ANOVAs) including the within-subjects factor Hand (left vs. right) and Temporal Reference (past vs. future) and the between-subjects factor Group (1 to 4) were performed on reaction time (RT) and on the percentage of correct responses (PC) in R (version 2.11.1). Additionally, we conducted by-item analyses with the factors Hand and Temporal Reference. Note that the factors Group and Hand are nested in the by-item analyses. In order to maintain a factorial design, we removed the factor Group in the by-item analyses.

2.2.1. RT

The overall mean RT of all correct keypresses was 2806 ms ($SD =$ 927 ms). Participants responded significantly faster to future sentences than to past sentences (2661 ms vs. 2954 ms), which was reflected in a main effect of factor Temporal Reference, $F_1(1, 48) = 81.75$, $p < .001$. Response speed did not significantly differ between the two hands, $F_1(1, 48) = 0.15$, $p = .697$. Most importantly and consistent with our hypothesis, a congruency effect emerged, reflected in a significant interaction between the factors Temporal Reference and Hand, $F_1(1, 48) = 4.40$, $p = .041$. Participants responded faster to past sentences with the left hand than with the right one (2885 ms vs. 3024 ms) and faster to future sentences with the right hand than with the left one (2606 ms vs. 2716 ms; see Fig. 1, upper panel). Finally, there was a three-way interaction of Temporal Reference, Hand, and Group, $F_1(3, 48) = 5.38$, $p =$ .003. This interaction effect merely reflects the usual finding that mean RT decreases with practice. Overall, RT decreased from 2890 ms in the first half of the experiment to 2707 ms in the second half (see Table 2 and Ulrich et al., 2012, for details why this three-way interaction reflects a practice effect).

These F_1-results were confirmed in a by-item analysis. Again a main effect of the factor Temporal Reference, $F_2(1, 38) = 7.95$, $p = .008$, was detected, but no one of the factor Hand, $F_2(1, 38) = 0.33$, $p = .568$. Furthermore, a significant interaction of the factors Temporal Reference and Hand, $F_2(1, 38) = 16.29$, $p < .001$, emerged.

2.2.2. PC

The overall PC was 97.8%. Participants correctly refrained from responding when a nonsensical sentence was presented in 98.0% of the nonsense trials. When a sensible sentence appeared, they pressed the right key in 97.5% of the sensible trials.

An ANOVA was performed on the percentage of correct responses to sensible sentences. Only the factor Temporal Reference showed a marginally significant main effect, $F_1(1, 48) = 3.48$, $p = .068$, i.e. participants responded more often correctly to future sentences than to past sentences (98.3% vs. 96.7%). Again, there was no main effect of the factor Hand, $F_1(1, 48) = 0.05$, $p = .819$. Participants tended to respond to future sensible sentences more correctly with the right hand than with the left one (98.9% vs. 97.7%) and to past sensible sentences more correctly with the left hand than with the right one (97.5% vs. 96.0%) although this interaction did not reach statistical significance, $F_1(1, 48) = 1.63$, $p = .207$ (see Fig. 1, lower panel).

The by-item analysis revealed similar results. There was neither a significant main effect of Temporal Reference, $F_2(1, 38) = 2.34$, $p = .135$, nor a main effect of Hand, $F_2(1, 38) = 0.05$, $p = .821$, and also no significant interaction of these two factors, $F_2(1, 38) = 2.55$, $p = .119$.

Experiment 1 clearly supports the existence of a left-to-right mental timeline, showing faster responses (about by 120 ms) when the response assignment between temporal sentence information and key side is congruent. Specifically, when a past-related sentence based on a retrospective verb required a left-hand response and a future-related sentence based on a prospective verb required a right-hand response, mean RT was shorter than when the response assignment was reversed. In sum then, the space–time congruency effect observed in Experiment 1 allows us to conclude that the left-to-right mental timeline is not only connected to explicitly deictic expressions (i.e. past/future tense ore deictic temporal adverbials) but can also be triggered in a more indirect way by a conspiracy of grammatical present tense

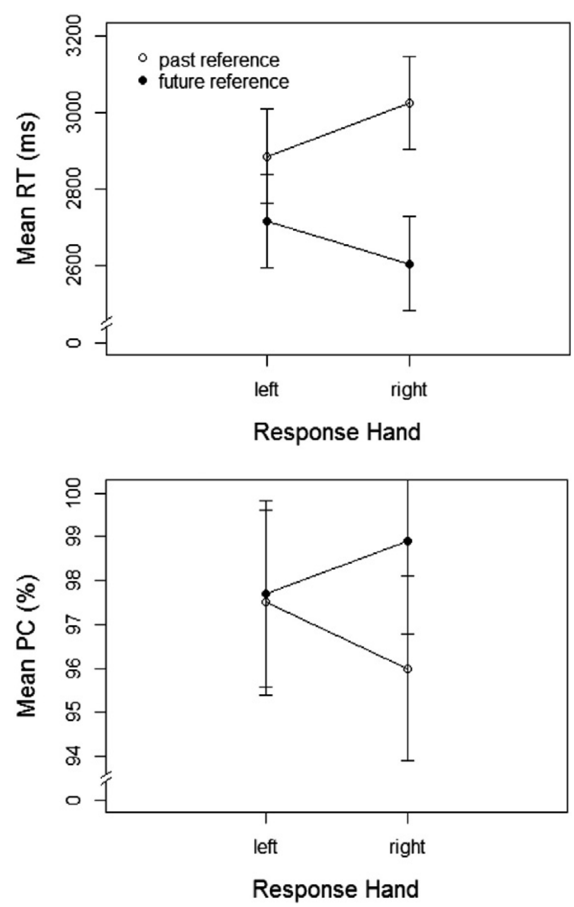

Fig. 1. Experiment 1: mean reaction times (RT; upper panel) and percentage of correct responses (PC; lower panel) as a function of Temporal Reference and Response Hand. Error bars show 95%-confidence intervals for the interaction between Temporal Reference and Hand.
The error bars were computed as recommended by Masson and Loftus (2003).

Table 2
Mean reaction times (RTs, in ms) and percentages of correct responses (PCs) as a function of Temporal Reference, Hand, and Group. Results from the first half of the experiment are in italics.

Hand	Temporal Reference			
	Past		Future	
	RT	PC	RT	PC
Group 1 (list A/congruent–list B/incongruent)				
Right	2858	100	*2815*	*100*
Left	*3043*	*96.9*	2463	99.2
Group 2 (list A/incongruent–list B/congruent)				
Right	*3266*	*93.9*	2587	98.5
Left	2879	97.7	*2948*	*97.7*
Group 3 (list B/congruent–list A/incongruent)				
Right	2932	93.1	*2476*	*97.0*
Left	*2821*	*96.2*	2756	99.2
Group 4 (list B/incongruent–list A/congruent)				
Right	*3051*	*97.0*	2541	100
Left	2799	99.2	*2699*	*94.6*

information, the lexical semantics of retrospective/prospective verbs and the semantics of event nominals.

3. Experiment 2

Having established the cognitive availability of a mental timeline in connection with retrospective and prospective verbs in terms of a space–time congruency effect, the main goal of Experiment 2 was to investigate in more detail the nature of this congruency effect. More specifically, Experiment 2 examined whether the congruency effect obtained in Experiment 1 is the sign of an automatic activation process. This experiment emulated a SNARC-like paradigm (Dehaene et al., 1993) along the lines of Experiment 2 from Ulrich and Maienborn (2010). If spatial schemata become automatically activated during the processing of temporal sentence information, the space–time congruency effect observed in Experiment 1 should also emerge in a task with task-irrelevant temporal information. Specifically, participants performed a judgment about the sensicality of a sentence, but not about its relation to the past or the future. Thus, the temporal information of a sentence was no longer a task-relevant dimension for selecting the correct response. If the mechanism underlying the space–time congruency effect, however, becomes active as soon as temporal information is processed, one should also observe a space–time congruency effect on RT. Furthermore, in order to make sure that participants processed thoroughly the meaning of the sentence, they were asked a forced-choice question concerning the content of the sentence at the end of some randomly selected trials.

3.1. Method

3.1.1. Participants

A fresh sample of 52 volunteers (35 female and 17 male) participated in this 20-min experiment for a payment of 5 €. They were all native speakers of German. Mean age was 24.6 years ($SD = 3.5$ years). All but five participants reported to be right-handed. Participants were naive with respect to the experimental hypothesis. All participants gave at least 90% correct responses and therefore the data of all participants were included into data analysis.

3.1.2. Apparatus and stimuli

These were the same as in Experiment 1.

3.1.3. Procedure

The procedure was the same as in Experiment 1 except for the following two changes. First, participants were asked to respond whether the sentences were sensible or not. In the first condition (cond 1) they had to press the right key for responding "yes" (sensible) and the left key for responding "no" (nonsensical), and in the other condition (cond 2) this assignment was reversed. Half of the participants started with cond 1 in the first part of the experiment and switched to cond 2 half-way through the experimental session for the second part. The other half proceeded in the reversed order. As in Experiment 1, the stimulus material was divided into two lists (A and B), thus yielding four groups of participants: Group 1 began with list A in cond 1 in the first part and switched to list B in cond 2 in the second part of the experiment, the other three groups proceeded as follows: Group 2: list A (cond 2)–list B (cond 1); group 3: list B (cond 1)–list A (cond 2); group 4: list B (cond 2)–list A (cond 1). One session consisted of 80 sentences plus seven practice trials with visual feedback before each part of the experiment. The duration of the sentence presentation was reduced to 5 s in this experiment. Note that there were no nogo-trials in Experiment 2.

Second, at the end of 40% of all trials, participants had to respond to a yes/no question concerning the content of the preceding sentence. This question concerned the temporal content or related to other aspects of the content (see the illustrations in (9) and (10)).

(9) Sentence (sensible):	Der Professor kündigt den Gastvortrag an. 'The professor announces the guest lecture.'
Question:	Hat der Gastvortrag bereits stattgefunden? 'Did the guest lecture already take place?'
(10) Sentence (nonsensical):	Der Spekulant büßt für die hinkende Farbe. 'The speculator atones for the limping color.'
Question:	Rührt der Spekulant in der hinkenden Farbe? 'Does the speculator stir in the limping color?'

Participants were asked to respond to these questions also with a left or right keypress. The yes/no assignment of the keys corresponded to the assignment that was used to respond to the main task (sensicality judgment). The next trial started after the keypress response or 6 s after the onset of the question if no response was made. Again, visual error feedback on both judgments was only given during practice blocks.

3.2. Results and discussion

Separate ANOVAs with the within-subjects factors of Temporal Reference (past vs. future),[3] Hand (left vs. right), and Sentence Content (sensible vs. nonsensical) and the between-subjects factor Group (1–4) were performed on mean RT and PC. As in Experiment 1, by-item analyses including the same factors except Group were conducted for the dependent variables. Again, we omitted the factor Group in the by-item analyses to maintain a factorial design. Fig. 2 depicts the mean of RT and PC as a function of Temporal Reference and Hand separately for sensible and nonsensical sentences.

3.2.1. RT

The overall mean RT was 2288 ms ($SD = 702$ ms) and thus about 500 ms shorter than that in Experiment 1, a difference which is probably due to the easier task in Experiment 2, where participants had to classify only the content of the sentences and not both their content and their temporal reference. Two significant main effects emerged. First, participants responded faster to sensible than to nonsensical sentences (2173 ms vs. 2404 ms), $F_1(1, 48) = 61.34$, $p < .001$. Second and like in Experiment 1, they responded faster to future sentences than to past sentences (2228 ms vs. 2348 ms), $F_1(1, 48) = 60.08$, $p < .001$. As before, the main effect of factor Hand was not significant, $F_1(1, 48) = 0.30$, $p =$

[3] Note that the nonsensical sentences with retrospective and prospective verbs are not always clearly related to past and future (see the examples in (8) and the remarks on (7)). Nevertheless, we maintain this terminology in Experiment 2 and 3 for the sake of simplicity.

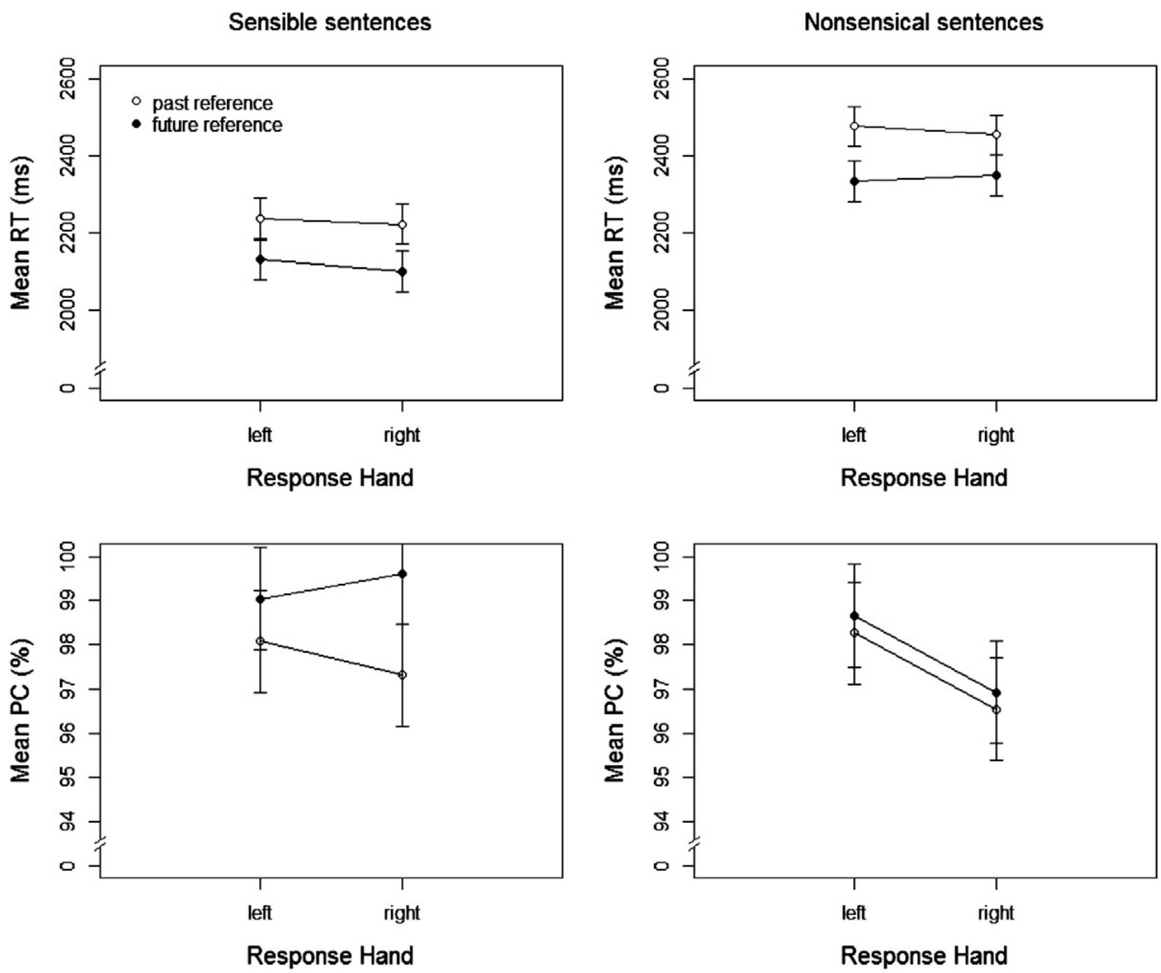

Fig. 2. Experiment 2: mean reaction times (RT) and percentage of correct responses (PC) as a function of Temporal Reference and Response Hand separately for sensible sentences (left panels) and for nonsensical sentences (right panels). Error bars show 95%-confidence intervals for the interaction between Temporal Reference and Hand.
The error bars were computed as recommended by Masson and Loftus (2003).

.586. In contrast to the prediction of the automatic activation hypothesis, there was no significant interaction of the factors Temporal Reference and Hand, $F_1(1, 48) = 0.05$, $p = .826$, nor a three-way interaction of the factors Temporal Reference, Hand, and Sentence Content, $F_1(1, 48) = 0.83$, $p = .367$. Likewise, the interaction between Hand and Sentence Content and the interaction between Temporal Reference and Sentence Content did not reach significance ($F_1 < 1$). Finally, there were again additional effects of the factor Group that are all related to practice: There was an interaction of Hand and Group, $F_1(3,48) = 3.10$, $p = .035$, and again a three-way interaction of Hand, Sentence Content, and Group, $F_1(3,48) = 23.50$, $p < .001$ (see Table 3 for details), which is due to a practice effect and again replicates the analogous practice effect observed in the study of Ulrich et al. (2012).

A by-item analysis yielded analogous results. As before, the main effects of the factors Sentence Content, $F_2(1, 76) = 22.38$, $p < .001$, and Temporal Reference, $F_2(1, 76) = 6.36$, $p = .014$, yielded statistically reliable main effects, whereas the factor Hand was again not significant, $F_2(1, 76) = 0.43$, $p = .514$. There also was no significant interaction of the factors Temporal Reference and Hand, $F_2(1, 76) = 0.13$, $p = .722$, and no significant three-way interaction of all factors, $F_2(1, 76) = 0.50$, $p = .483$.

3.2.2. PC

All participants produced more than 93.0% correct responses. The overall PC to the question whether the sentence was sensible or not was 98.1%. An ANOVA on PC revealed a significant main effect of factor Temporal Reference, $F_1(1, 48) = 6.30$, $p = .016$, i.e. participants responded more often correctly to future sentences than to past sentences (98.6% vs. 97.6%). Factor Hand was marginally significant, $F_1(1, 48) = 2.99$, $p = .090$. Responses with the left hand tended to be more correct than responses with the right hand (98.5% vs. 97.6%). Sentence Content was not significant, $F_1(1, 48) = 2.36$, $p = .131$. Again, this ANOVA revealed no significant interaction between Temporal

Table 3
Mean reaction times (RTs, in ms) and percentages of correct responses (PCs) as a function of Sentence Content, Hand, and Group. Results from the first half of the experiment are in italics.

Hand	Sentence Content			
	Sensible		Nonsensical	
	RT	PC	RT	PC
Group 1 (list A/condition 1–list B/condition 2)				
Right	*2429*	*96.9*	2392	99.2
Left	2180	97.3	*2709*	*98.1*
Group 2 (list A/condition 2–list B/condition 1)				
Right	1922	100	*2437*	*96.2*
Left	*2154*	*98.1*	2174	99.6
Group 3 (list B/condition 1–list A/condition 2)				
Right	*2217*	*98.1*	2340	97.3
Left	2197	98.9	*2553*	*98.9*
Group 4 (list B/condition 2–list A/condition 1)				
Right	2087	98.9	*2441*	*94.2*
Left	*2205*	*100*	2185	97.3

Reference and Hand, $F_1(1, 48) = 0.68$, $p = .412$, and no significant three-way interaction between all three factors, $F_1(1, 48) = 0.81$, $p = .372$. In addition a practice related interaction of Sentence Content and Group emerged, $F_1(3, 48) = 3.27$, $p = .029$.

A by-item analysis produced similar results. The main effects of Temporal Reference, $F_2(1, 76) = 4.24$, $p = .043$, and Hand, $F_2(1, 76) = 4.53$, $p = .037$, attained statistical significance, the main effect of Sentence Content was marginally significant, $F_2(1, 76) = 3.47$, $p = .066$. There was no significant interaction between Temporal Reference and Hand, $F_2(1, 76) = 0.62$, $p = .435$, and also the three-way interaction of all factors was insignificant, $F_2(1, 76) = 0.62$, $p = .435$. A marginally significant interaction between Hand and Sentence Content emerged, $F_2(1, 76) = 3.63$, $p = .061$.

In sum, the results of Experiment 2 are consistent with the notion that the space–time congruency effect observed in Experiment 1 is not the sign of an automatic process. Even if there is a secondary task that forces participants to process explicitly the content of the sentence, this does not yield results consistent with an automatic activation of the mental timeline.

4. Experiment 3

Sell and Kaschak (2011) reported an automatic activation of the mental timeline when participants made sensicality judgments about each sentence by moving their right hand either away from or toward their body. However, when their participants were asked to respond by a single keypress with the left or the right hand, the compatibility effect between time and space disappeared. Therefore, it seems possible that the null-effect observed in Experiment 2 simply reflects the fact that automatic effects can only be observed when participants must operate their manual responses along the front-back axis. Thus, Experiment 3 replicated Experiment 2 with the exception of the response mode, which was identical to the back–front movement condition by Sell and Kaschak. In addition, we tested 100 instead of 52 participants as in Experiment 2 to further increase the statistical power of the design. If response mode matters, we expect to observe a space–time congruency effect in this experiment.

4.1. Method

4.1.1. Participants

One hundred participants were tested in this experiment. None of them had participated in Experiment 1 or 2. Like in these previous experiments, one session took about 20 min and participants received 5 € for payment. They were all native speakers of German and left naive with respect to the experimental hypothesis. 66 of them were female and 34 male, 13 reported to be left-handed. Mean age was 24.0 years ($SD = 4.8$ years). All participants gave at least 93% correct responses to the question concerning the sensicality of the sentences, therefore the data of all participants were included into the final data analysis.

4.1.2. Apparatus

This was the same as in Experiments 1 and 2, except for the response device. Following Sell and Kaschak (2011), a common QWERTZ computer keyboard with three modified keys was used. The height of the "s" key, the "x" key and of the "4" key on the number block were increased by fixing small round plastic blocks on them. The plastic block on the "s" key was red, the block on the "x" key silver, and the block on the "4" key had a white color. This keyboard was oriented lengthwise, so that for the participants in the "away" condition the red "s" response key was the nearest and the white "4" the furthermost response key, whereas for the participants in the "toward" condition the "4" was the nearest and the "s" the furthermost response key.

4.1.3. Stimuli

These were the same as in Experiments 1 and 2.

4.1.4. Procedure

Participants were given written information about the task, and were instructed to carefully read the sentences, and to press all response keys only with the index finger of their right hand. Like in Experiment 2, they had to judge the sensicality of the sentences. Following the experimental procedure described in Sell and Kaschak (2011), participants first had to press the red "s" key to make a sentence appear, which was sensible or nonsensical with equal probability. While reading the sentence they had to keep the "s" key pressed, otherwise the sentence would disappear. After reading the sentence, participants had to decide whether it was sensible or nonsensical. If they judged the sentence to be sensible, they had to release the "s" key (causing the disappearance of the sentence), move their hand to the white "4" key and press it. If they judged a sentence to be nonsensical, they had to press the silver "x" next to the "s" key. After pressing the "4" or "x" key, participants received a visual error feedback which appeared in the middle of the screen for 1000 ms. Then the screen remained blank, until the "s" key was pressed again and the next sentence appeared.

At this stage a yes/no question concerning the content of the preceding sentence appeared in 40% of all trials instead of the next sentence. Like the sentences, this question was only visible as long as the "s" key was pressed down. To answer the question, participants had to release the "s" key (causing the disappearance of the question) and press the "4" key if they answered with "yes" and the "x" key if they answered with "no". After a visual error feedback, the screen again remained blank, until the "s" key was pressed and the next sentence appeared. Sentences, questions, and feedback were presented with a short delay of 100 ms after each keypress.

Since response direction, i.e. whether participants responded to sensible sentences with an arm movement away or toward themselves, was manipulated between subjects, there were only two groups in this experiment, corresponding to the "away" and the "toward" condition. Half of the participants were assigned to the "away" group; for them the "s" key was near their body and they had to move their hand forward (away from themselves) to press the "4" key on the number block. The remaining participants were assigned to the "toward" group, i.e. the "s" key was relatively far away from their body and they had to move their hand backwards (toward themselves) to press the "4" key. Participants were randomly assigned to one of the two groups. One session consisted of 80 sentences (40 sensible and 40 nonsensical) plus seven practice trials at the beginning.

4.2. Results and discussion

Separate ANOVAs with the within-subjects factor Temporal Reference (past vs. future) and the between-subjects factor Response Direction (away vs. toward) were performed on mean reaction time and percentage of correct answers. Furthermore, we conducted by-item analyses with the within-items factor Response Direction and the between-items factor Temporal Reference. Note that in this experiment the factor Response Direction corresponds to the factor Group, because one participant either had to move his/her hand away or toward his/her body. Like in the study of Sell and Kaschak (2011), we analyzed all reading times (RTs) to sensible sentences, that is, the time from pressing the "s" key until releasing it.

Fig. 3 depicts the mean of RT and PC as a function of Temporal Reference and Response Direction.

4.2.1. RT

The overall mean RT of all correctly performed sensible trials was 2304 ms ($SD = 1065$ ms). Like in Experiments 1 and 2, participants responded significantly faster to future sentences than to past sentences (2229 ms vs. 2380 ms), which was reflected in a main effect of Temporal Reference, $F_1(1, 98) = 23.20$, $p < .001$. There was no significant main effect of the between-subjects factor Response Direction in the by-subjects analysis, $F_1(1, 98) = 2.64$, $p = .108$, although reaction times of the "away" group were shorter than that of the "toward" group (2220 ms vs. 2388 ms). Most important, however, like in Experiment 2 and in contrast to the results reported in Sell and Kaschak (2011), there was no interaction between the factors Temporal Reference and Response Direction, $F_1(1, 98) = 0.73$, $p = .395$.

A by-item analysis produced similar results. There was a marginally significant main effect of Temporal Reference, $F_2(1, 38) = 3.16$, $p = .084$, and a significant main effect of Response Direction, $F_2(1, 38) = 29.43$, $p < .001$. Again, no interaction between the two factors emerged, $F_2(1, 38) = 0.45$, $p = .505$.[4]

4.2.2. PC

The overall PC to the question whether a sentence was sensible or not was 98.3%. All participants gave at least 93.0% correct responses. Mean PC to all sensible sentences was 98.0% (to nonsensical sentences 98.5%). An ANOVA on PC to sensible sentences revealed a significant main effect of Temporal Reference, $F_1(1, 98) = 13.60$, $p < .001$: Participants responded more often correctly to future sentences than to past sentences (98.8% vs. 97.3%). Concerning the factor Response Direction, mean PC of the "away" condition was exactly the same than that of the "toward" condition (98.1%). No interaction of the factors Temporal Reference and Response Direction emerged, $F_1(1, 98) = 0.24$, $p = .624$.

These results were confirmed by a by-item analysis. Only the factor Temporal Reference showed a significant main effect, $F_2(1, 38) = 5.36$, $p = .026$. There was no interaction between Temporal Reference and Response Direction, $F_2(1, 38) = 0.15$, $p = .701$.

In conclusion, the results of this experiment reject the idea that the null-effect observed in Experiment 2 is due to an inappropriate response mode. The results further strengthen the notion that the congruency effect observed in Experiment 1 is not caused by an automatic activation of the mental timeline.

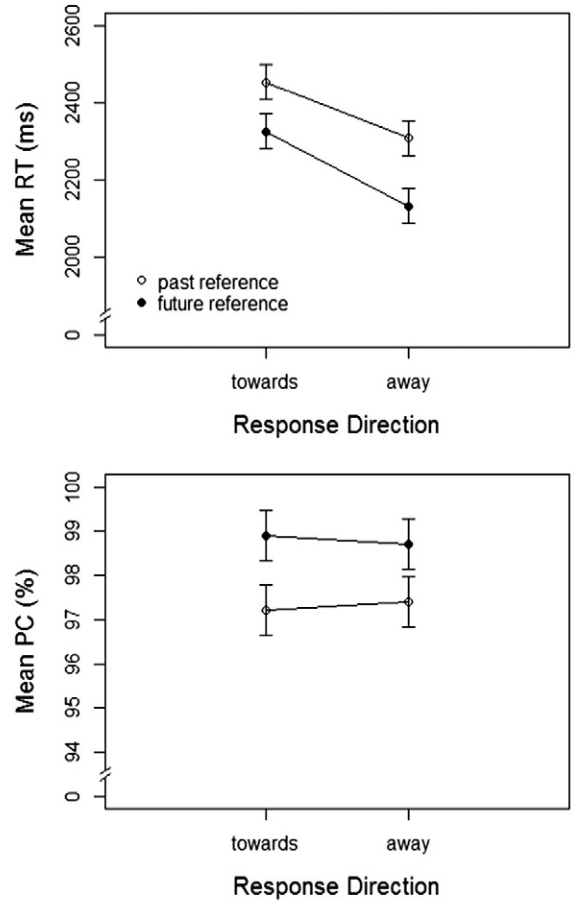

Fig. 3. Experiment 3: mean reaction time (RT; upper panel) and percentage of correct responses (PC; lower panel) as a function of Temporal Reference and Response Direction. Error bars show 95%-confidence intervals for the interaction between Temporal Reference and Response Direction.
The error bars were computed as recommended by Masson and Loftus (2003).

5. General discussion

Previous experimental studies have shown that people code deictic time in terms of a mental timeline which typically runs from left to right or from back to front (e.g., Eikmeier et al., 2013; Ouellet et al., 2010; Santiago et al., 2007; Torralbo et al., 2006; Ulrich & Maienborn, 2010; Ulrich et al., 2012). Furthermore, these studies have demonstrated that an activation of the mental timeline can be triggered by lexical expressions and grammatical means which refer explicitly to the past or to the future, i.e. deictic temporal adverbials and tense. These studies have revealed a space–time congruency effect in terms of faster responses to past- and future-related linguistic information when the response direction is compatible with the left-to-right or back-to-front orientation of the mental timeline than when it is not.

The cognitive function of this mental timeline during the processing of linguistic information is an unsettled question, that is: What is the nature of this mental timeline and what is its cognitive purpose? In particular, is such a spatial construal of deictic time a necessary ingredient of language understanding? When processing the temporal information of linguistic expressions, do we automatically recur to such spatial schemata? If so, this would suggest that the mental timeline is functionally involved in the construction of linguistic meaning concerning time. So far, the experimental evidence to this issue is inconclusive. On the one side, the studies of Ulrich and Maienborn (2010) and Ulrich et al. (2012) argue against an automatic activation of the mental timeline for the meaning composition at sentence level. Specifically, they only observed a space–time congruency effect for past- vs. future-related sentences when the temporal information was task-relevant (i.e. when participants were asked to classify the sentences as relating to the past or future). But this signature of the mental timeline disappeared when temporal information was task-irrelevant (i.e. when participants were asked to decide on the sensicality of sentences). On the other side, Sell and Kaschak (2011) observed an automatic activation of the mental timeline for the processing of sentences in small stories. Specifically, they found a space–time congruency effect for past- or future-related sentences when temporal information is task-irrelevant (i.e. sensicality judgment), but only when the temporal break between the narrated events was sufficiently large. A possible explanation for these diverging results could be that the mental timeline is not functionally involved in the processing of simple sentences which only express the content and temporal location of a single event and thus are less demanding with respect to the processing of temporal information, but becomes automatically activated at discourse level, when several events are temporally ordered by locating them on the mental timeline.

The aim of the present study was to contribute to the clarification of this issue by investigating the processing of still simple, yet temporally more demanding sentences, which involve the expression of two temporally related events. More precisely, the present study had two goals. First, it examined whether the left-to-right mental timeline can also be triggered by linguistically more complex constellations in which the reference to past and future is not established by overt deictic means but in a more intricate way, which presumably requires an

[4] The overall mean movement time from the "s" to the "4" key was 622 ms ($SD = 719$ ms). Movement times after future sentences were shorter than after past sentences (609 ms vs. 634 ms), but this effect did not reach statistical significance, $F_1(1, 98) = 1.16$, $p = .285$, $F_2(1, 38) = 1.10$, $p = .302$. Likewise, movement times in the "away" condition were shorter than in the "toward" condition (597 ms vs. 646 ms). This effect was only significant in the by-item analysis, $F_1(1, 98) = 1.86$, $p = .176$, $F_2(1, 38) = 5.28$, $p = .027$. No interaction emerged ($Fs < 1$).

especially demanding processing of temporal information. Secondly, the study assessed whether the processing of such two-event sentences automatically activates the left-to-right/back-to-front mental timeline. To this end, the present study investigated the processing of sentences with retrospective verbs (e.g., *to remember*, *to regret*, *to reconstruct*) and prospective verbs (e.g., *to expect*, *to announce*, *to predict*). If put in present tense, these verbs locate a second event introduced by their internal argument either in the past (for retrospective verbs; e.g., *The witness remembers the pistol-shot*) or in the future (for prospective verbs; e.g., *The professor announces the guest lecture*).

Experiment 1 was designed analogously to the first experiment reported in Ulrich and Maienborn (2010). In this experiment, past- or future-relatedness of the sentences was task-relevant, and a clear space–time congruency effect was obtained. This reinforces the psychological reality of the mental timeline and demonstrates its broader availability and scope. And, more importantly, it shows that the mental timeline is not only linked to overtly deictic linguistic material such as past or future tense or deictic temporal adverbials but can also be evoked in a more intricate way by combining the lexical meaning of a retrospective/prospective verb with present tense and the semantics of an embedded event argument. That is, reference to the mental timeline may also be construed through the compositional construction of sentence meaning.

Experiment 2 examined whether understanding a simple sentence with a retrospective/prospective verb would automatically activate the left-to-right mental timeline. If spatial schemata are involved in the processing of these temporally more demanding two-event sentences, the space–time congruency effect on response time should also emerge in a task when time–space association is task-irrelevant, similar to the SNARC effect (Dehaene et al., 1993) or to the Simon effect (Simon & Rudell, 1967). Yet, as in the studies of Ulrich and Maienborn (2010) and Ulrich et al. (2012), the effect disappeared when participants classified the displayed sentences according to their sensicality (sensible vs. nonsensical), rather than their temporal orientation (past- or future-related). Note that the experiment made sure that participants read the sentences carefully by including additional questions relating to the content. Nevertheless, no sign of activating the mental timeline was observed.

Experiment 3 tested the automatization hypothesis under the experimental design of Sell and Kaschak (2011). That is, the front-back axis was used as response mode and participants had to perform a movement in order to respond. Yet, even under these conditions no space–time congruency effect emerged.

The results of Experiments 1–3 are consistent with the non-automatic memory account of the space–time congruency effect proposed in Ulrich and Maienborn (2010) according to which this effect is task-dependent and reflects a facilitated memory access. Our results support the conclusion that even under the given especially demanding circumstances, which require more thorough processing to determine the temporal location of events, spatial schemata are not automatically activated, suggesting that the mental timeline is not functionally involved in the processing of sentence meaning. Moreover, the experiments demonstrate that even if two events are involved and are put into a temporal order, as in the case of retrospective/prospective sentences, an activation of the mental timeline does not seem to be essential for the linguistic processing and, hence, does not appear to provide a cognitive benefit.

It should be noted that the two events expressed by retrospective/prospective sentences in the present study are always clearly distinct and temporally separated. Contrary to the sentence material used by Sell and Kaschak (2011), in our case there is no danger of conflating the two events into one single event. That is, Sell and Kaschak had to make sure with a sufficiently large temporal shift that the second event of their small stories (e.g., learning about paintbrushes in (2)) was not only taken as an elaboration of the first event (e.g., taking a painting class in (1)) but was understood as an independent narrative step (via narration; see, e.g., Asher and Lascarides (2003)). More specifically, the second event in the stories used by Sell and Kaschak was a constitutive part of the more global first event description. Hence, explicit linguistic means in terms of a temporal adverbial expressing a large time shift were required in order to legitimate the additional effort of zooming in into this global event and considering the temporal sequence of internal subevents (i.e., taking a painting class involves, e.g., first, experimenting with colors, then, getting an introduction into perspectives, then, learning about paintbrushes, etc.). No such measures are necessary in our case. A sentence about, e.g., remembering a pistol-shot or announcing a guest lecture is necessarily understood as expressing two independent and temporally separate events which occupy distinct places on the mental timeline (i.e., a pistol-shot followed by its remembrance or an announcement followed by a guest lecture). Note furthermore that, according to our world knowledge, event sequences such as a pistol-shot and a witness remembering the pistol-shot in court or the announcement of a guest lecture and the guest lecture taking place are typically separated by rather large time shifts. Thus, although the temporal conditions of the sentence stimuli in the present study were more favorable in this respect compared to the sentence material used by Sell and Kaschak, no space–time congruency emerged. The results of Experiments 2 and 3 therefore support the conclusion that the relevant factor driving an automatic activation of the mental timeline is not the number of linguistically expressed events. Even if two events are involved, from which one is located in the past/future, no sign of an automatic activation of the mental timeline is observed. In view of these results and the findings by Sell and Kaschak, it seems reasonable to assume that the relevant factor that calls for an automatic activation of spatial schemata when processing temporal information might rather be the number of sentential units that are to be processed. That is, when building up a discourse model and updating it each time, when the semantic content of a new sentential unit is integrated into the existing model, activating spatial schemata may provide a benefit for organizing and keeping track of the temporal order of the narrated events. Within a single sentence though, processing multiple events which are temporally ordered and deictically located through grammatical means and lexical predicate-argument structure does not seem to require additional spatial support.

More generally speaking, the results of the present study support the assumption that linguistic structure in a narrow sense, i.e. core grammar and lexical predicate-argument structure, does not hinge upon a spatial construal of deictic time. The activation of a mental timeline appears to be of no particular benefit for the compositional construction of sentence meaning. One may speculate whether a spatial grounding of the abstract category of time only becomes linguistically relevant beyond the realms of sentential meaning composition driven by the core grammar, that is, in multiple-sentences discourse. Future research is necessary to examine further this hypothesis. The present study does not reject the view that the abstract domain of time is conceptualized in terms of the more concrete, experientially accessible domain of space. Yet it casts doubts on the ubiquity and obligatoriness of such a spatial construal of time. Within the realms of grammar, abstract notions such as time appear to exist on their own.

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