CHAPTER 6

The mental timeline during the processing of linguistic information*

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There is ample evidence that people use spatial concepts to think and speak about time. Consistent with this notion, recent reaction time experiments have documented that the spatial coordinates of responses influence speeded decisions regarding temporal information. Specifically, classifying temporal linguistic information produces a space-time congruency effect on reaction time when responses with the left and right hand are arranged on the left-right axis. A similar effect can be observed for responses that consist of movements along the back-front axis. These findings are consistent with the view that time runs from left to right or from back to front. In the present article we review these results and assess the linguistic relevance of these two mental timelines for the comprehension of linguistic information at the word and sentence level.

Keywords: spatial representation of time, mental timeline, reaction time, comprehension, linguistic information processing, conceptual metaphor

1. Mental representation of time

At a phenomenological level, time appears to be an essential component of our cognition – time structures our thoughts and thus enables us to understand the world in which we live. Moreover, the notion of time is important for planning actions and for understanding the sequence of external events that we perceive. It is hard to imagine how our thinking would operate without the experience of time. Although time is fundamental to our cognition, the concept of time itself is elusive. Time cannot be traced back to basic phenomena like other physical

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concepts such as temperature (which can be traced back to moving particles) or a rainbow (which can be traced back to refraction of light). In fact, some have even argued that time is not an empirical primitive of the physical world (see Evans 2006). Since there is no adequate physical stimulus of time, there can be also no receptor system associated with time like for vision or audition (e.g., Grondin 2001). Nevertheless time, feels cognitively real and functional. This prompts the question how time emerges within our cognitive system.

In response to this question, it has been repeatedly argued that we heuristically use space to conceptualize time (Burr, Tozzi, and Morrone 2007; Gentner, Imai, and Boroditsky 2002). The notion that our thinking about time roots in our thinking about space is shared by philosophers, linguists, and cognitive psychologists (e.g. Casasanto and Boroditsky 2008; Evans 2006; Fraser 1966; Haspelmath 1997; Klein 2009; Tversky, Kugelmass, and Winter 1991). Spatial representations are most likely richer than temporal ones, because the former are built up through concrete sensorimotor experiences (Talmy 1988). Therefore it has been assumed that time is conceptualized in terms of space. This view has been called the *spatial metaphor of time* (e.g., Clark 1973: 50). It can be conceived as a corollary of the general conceptual metaphor view, which assumes that all abstract concepts are built on a set of basic schemata that people acquire through bodily interactions with the world (Lakoff and Johnson 1980; Mandler 1992).

The spatial metaphor of time is concordant with our introspection about time since we can imagine space without conceiving time but we cannot imagine time without conceiving space.[1] Moreover, this spatial metaphor of time is also evident when people communicate about time. It is nearly impossible to talk about time without using expressions that refer to space or motion (e.g., *the exam is behind me; the meeting has been moved forward to Friday*). Although we can directly observe a car moving forward, we can only imagine that a meeting has been moved forward (see Casasanto, Fotakopoulou, and Boroditsky 2010; McGlone and Harding 1998). It is therefore not surprising that the vocabulary of time has spatial roots in natural languages across the world (Haspelmath 1997; Lakoff and Johnson 1980; Núñez and Cooperrider 2013; Núñez and Sweetser 2006). Haspelmath's crosslinguistic survey of data from 53 different languages shows that the overwhelming majority of temporal expressions originate from

1. In a survey, we asked 110 German students to answer the following two questions: (a) Can you imagine space without imaging time? (yes/no) (b) Can you imagine time without imaging space? (yes/no). Consistent with the notion that we can think about space without thinking about time but not the reverse, 73.6% and 31.8% answered (a) and (b) with "yes", respectively. A statistical test of correlated proportions showed that this difference is highly significant, $\chi^2 = 25.96$, $df = 1$, $p < 0.001$.

spatial expressions. Moreover, young children acquire spatial expressions such as *there* and *here* earlier than the related temporal counterparts *then* and *now* (e.g. Clark 1973; Graf 2006; Weissenborn 1988; however, see for example Richards and Hawpe 1981).

Space and motion are not the only metaphoric conceptualizations of time. Figurative speech suggests that time is sometimes also mentally equated with a valuable commodity, a limited resource, or money (e.g., *you are wasting your time*, *we run out of time*, *this meeting costs me three hours*; Evans 2006; Lakoff and Johnson 1980). However, these concepts of time are associated with duration rather than with deictic time or sequential time to which the spatial metaphor of time applies. Deictic time includes the concepts of 'past', 'present', and 'future' – the deictic time system allows one to refer to time relative to a temporal reference point, which is typically the time of utterance (e.g., *Alissa will go hiking;* the utterance precedes the event of Alissa going hiking). By contrast, the sequential time system does not require the concepts 'past', 'present', and 'future', yet allows a relative sequencing of events (e.g.*, summer comes after spring; Julika was born before Jens and Dominik;* Traugott 1978). These two time systems are often visualised by means of a timeline.

2. Mental timeline

Indeed, the notion that people employ spatial representations to think about time has received strong empirical support in the last 15 years. The results of several studies have suggested that people use a mental timeline that typically runs from back to front when thinking and talking about time (i.e., deictic time). On this sagittal axis, future is typically represented in front and past behind oneself, so that the ego represents the deictic center along this back-to-front mental timeline (see Núñez and Sweetser 2006, for the prominent exception of Aymara, which appears to support the reverse mapping with the past in front and the future behind). Moreover, there is also ample evidence that people involve the left-to-right axis when they think about time. On this transversal axis, the position of the present matches the spatial position of oneself; relative to this egocentric position the past is typically represented to the left and the future to the right. For a comprehensive description of these mental timelines, the reader is referred to the reviews of Núñez and Cooperrider (2013) and of Bender and Beller (2014).

In the following we review some empirical evidence that has been put forward that these timelines are psychologically real. After this review, we address the question whether these timelines are functionally involved in the comprehension of temporal expressions in natural language.

In an often cited work, Tversky et al. (1991) asked children to put stickers on a page. For example, one of these stickers represented time for breakfast and another one time for dinner. At the beginning of the task, the experimenter put a reference sticker in the middle of the page and indicated that this sticker represents lunch time. Responses were coded as left-to-right, right-to-left, top-to-bottom, or bottom-to-top depending on how children arranged the stickers relative to the reference sticker. Teenagers and adults also participated in this study and performed a similar task. There was a strong tendency for English-speaking children, teenagers, and adults to depict temporal concepts from left to right with the past to the left and the future to the right. This result supports the idea that people cognize time as running from the left to the right. Convergent evidence for such a left-to-right coding of time comes from studies investigating temporal gestures of American English speakers (Cooperrider and Núñez 2009). In addition, sign languages make use of the left-right axis when referring to the temporal sequence of events (Emmorey 2001).

For Hebrew and Arabic speakers, however, the right-to-left direction was dominant suggesting cultural differences in the direction of the mental timeline. This cultural difference has been confirmed in more recent studies (Fuhrman and Boroditsky 2010; Ouellet, Santiago, Israeli, and Gabay 2010) and has been attributed to differences in the preferred reading and writing direction across theses cultures. Accordingly, the direction of the orthographic system determines the direction of the transversal mental timeline (Ouellet, Santiago, Israeli, et al. 2010). This conclusion that the reading and writing direction influences the direction of the mental time line has been further strengthened by de Sousa (2012) showing that the dominant horizontal writing direction in Chinese (i.e., right-to-left before the 1950s; left-to-right during 1970s and later) influenced the orientation of the horizontal timeline differently for older compared to younger Chinese participants.[2]

An alternative approach for demonstrating the psychological reality of a transversal mental timeline was offered by studies that measured reaction time (e.g., Santiago, Lupiáñez, Pérez, and Jesús Funes 2007; Torralbo, Santiago, and Lupiáñez 2006; Ulrich and Maienborn 2010; Weger and Pratt 2008). In general, these studies require participants to process and respond to stimulus information that is related to the past or to the future. The amount of time that elapses between

2. It should be noted that a top-down mental timeline has been documented for Mandarin speakers, which also supports the notion that writing direction influences the orientation of the mental timeline, because Mandarin is also written and read from the top to the bottom (see for example, Bergen and Chan Lau 2012; Boroditsky 2001; Boroditsky, Fuhrman, and McCormick 2011; Tse and Altarriba 2008).

stimulus onset and the corresponding response is referred to as reaction time (RT). Changes in RT as a function of experimental condition are used to infer the cognitive mechanisms that operate between stimulus onset and the corresponding response (Sternberg 2001). Since the speed of mental processing is not under participants' control (Libet 2004: 54–56) and sometimes not even consciously accessible (Corallo, Sackur, Dehaene, and Sigman 2008), RT measurements are less prone to response biases such as demand characteristics than other behavioral measures (see also Fuhrmann et al. 2011). Accordingly, RT measurement is especially suited to tap on basic cognitive processes. The notion that the linkage of time and space is a fundamental feature of our cognitive system receives therefore especially strong support from RT studies.

Torralbo et al. (2006) were the first to demonstrate a space-time congruency effect on RT. For example, in Experiment 1 of their study, participants viewed on a computer screen a face silhouette in side view looking to the right or to the left. A word referring either to the past or to the future (e.g., Spanish dijo, *"s/he said")* was presented in front of or behind this face. Depending on the temporal reference of this word, participants were instructed to respond vocally either *pasado* ("past") or *futuro* ("future"). A trial was front-back congruent when a future (past) word appeared in front of (behind) the face. The onset of the vocal responses was approximately 15 ms shorter in congruent compared to incongruent trials. Their second experiment was identical to the first one, except that participants were now instructed to respond manually to the temporal content of the words. Specifically, participants responded with their left (right) hand to past (future) words. Surprisingly, the front-back congruency effect disappeared and a left-right congruency effect appeared. This time, responses were about 15 ms shorter when participants responded with their left (right) hand to past (future) words than when the mapping of past and future to the two hands was reversed. Although the results of Torralbo et al.'s study demonstrate a cognitive linkage between time and space, their results also indicate that space-time congruency effects depend on the interaction of response modality and the conceptual projection of space to time (i.e., on front-back vs. left-right projection). Further RT studies with manual responses provide convergent evidence for back-to-front coding of time (Sell and Kaschak 2011; Ulrich et al. 2012; however see Fuhrman et al. 2011).

Since the study of Torralbo et al. (2006), researchers have primarily focused on the left-right congruency effect and successfully replicated it for manual responses (Kong and You 2012; Ouellet, Román, and Santiago 2012; Ouellet et al. 2010; Santiago et al. 2007; Ulrich and Maienborn 2010; Weger and Pratt 2008). For example, Santiago et al. presented on each trial a single time-related word on the computer screen. Participants in their study were asked to make a speeded manual response to the temporal content of the word. Specifically, in the congruent condition, they were asked to respond with the left hand to past-related words and with the right hand to future-related words. This assignment was reversed in the incongruent condition. Again, shorter RTs were observed in the congruent than in the incongruent condition supporting the notion of a left-to-right timeline. Weger and Pratt (2008) observed a comparable effect when participants were asked to decide whether an actor became famous before or after they were born (e.g., *Charlie Chaplin* vs. *Tom Cruise*). Although the names of the actors did not convey explicit temporal information, manual RTs were also shorter when the stimulus–response mapping was compatible with a left-to-right representation of time.

While previous studies have demonstrated a left-right mapping of temporal expressions at the word level using isolated lexical items, Ulrich and Maienborn (2010) aimed at extending these studies to the processing of complete sentences, as it was unclear whether the mental timeline is likewise activated when temporal expressions are embedded in sentences. For example, neuro-cognitive research 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 than presented alone (Raposo, Moss, Stamatakis, and Tyler 2009). Interestingly, a reliable congruency effect emerged for the processing of temporal sentence information. In a similar vein, RT research employing event sequences in natural scenes provided evidence that mental representations of such sequences unfold from left to right in our minds (Fuhrman and Boroditsky 2010; Santiago, Román, Ouellet, Rodríguez, and Pérez-Azor 2010). These additional results hint towards the assumption that this left-right mental timeline is involved in several cognitive functions and is not just an epiphenomenon without any cognitive purpose.

Thus, the results of these RT studies support the psychological reality of a transversal as well as a sagittal mental timeline. As RT indexes the speed of sensorimotor and elementary decision processes, it seems plausible to assume that the linkage between time and space resides at a fundamental level within our cognitive system. The claim that the concepts of time and space are strongly linked at an elementary cognitive level was recently addressed by Eikmeier, Schröter, Maienborn, Alex-Ruf, and Ulrich (2013). The basic idea of this study was to compare the size of the space-time congruency effect on RT to a benchmark effect reflecting the upper bound that this congruency effect may attain. This benchmark was assessed for time-related stimuli and responses. Specifically, the stimulus material consisted again of time-related linguistic expressions. In the congruent condition, participants responded vocally with the word *past* to past-related information and with the word *futur*e to future-related information. In the incongruent condition, this assignment between stimuli and responses was reversed. The resulting benchmark congruency effect was compared to a space-time congruency effect obtained with the same stimuli and vocal responses using the space-related words *behind* and *in front*. The space-time congruency effect did not differ from the benchmark congruency effect. Therefore, this pattern of results indicates that the size of the space-time congruency effect attains the upper possible bound. A similar second experiment employed spatial stimuli. Specifically, the stimulus material consisted of tones that were presented in front of the participants or behind them. Participants were asked to respond to the location of the tone. In the benchmark condition of this experiment, participants responded vocally with the space-related words *behind* and *in front* whereas in the space-time congruency condition participants responded with the time-related words *past* and *future*. Again the space-time congruency effect was of the same size as the benchmark congruency effect and therefore at the upper possible bound. The observation of space-time congruency effects of the same size as the benchmark effects in both experiments suggests a strong linkage between space and time along the sagittal mental timeline.

The studies reviewed above revealed reliable space-time congruency effects for time-related judgments when responses where arranged along the transversal or the sagittal line. Therefore, one may accept the notion that the cognitive functions of these two timelines are equivalent. More recent results, however, challenge this view. For example, Walker, Bergen and Núñez (2014) found reliable space-time congruency effects for deictic and for sequential temporal judgments, when time-related linguistic phrases were presented via loudspeakers along the transversal axis, that is, to the left or to the right of the participant. By contrast, when these phrases were presented via speakers along the sagittal axis (i.e., in front of or behind the participant like in the study of Eikmeier et al. 2013), no space-time congruency effect emerged for deictic judgments. Most surprisingly, a space-time congruency effect was observed for sequential judgments with faster responses when phrases about earlier events were presented in the front instead behind the participant. Given such inconsistent results, it clearly seems premature to conclude that the transversal and sagittal timelines are of equal cognitive status. More research would be required to substantiate this view.

It must be noted, however, that the direction of the mental timeline is not hard-wired and thus fixed as a strong view of the metaphoric mapping theory might suggest. The results of some studies indicate substantial flexibility in the conceptual mapping of time onto space (Santiago, Román, and Ouellet 2011). For example, Casasanto and Bottini (2014) presented time-related expressions on a screen that was written either in standard orthography or in mirror writing. Whereas the standard orthography produced the usual left-to-right space-time congruency effect on RT; the mirror writing produced a reversed space-time congruency effect already after 48 trials, that is, the mental timeline was inverted after a few trials of practice. Similar results demonstrating flexible remapping of time and space were also reported by Boroditsky (2001). If temporal concepts would be grounded in low-level motor circuits, one would presumably expect a rather hard-wired linkage between our concepts of time and space that lacks such high flexibility. However, the results of some studies are at variance with this conclusion. For example, Miles, Nind, and Macrae (2010) report that people sway somewhat forward when they imagine future events and backward when they imagine past events. In addition, the processing of future-related words is speeded up when people are passively moved forward as compared to backward (Hartmann and Mast 2012). These results are consistent with the notion that temporal concepts are rooted in low-level motor circuits.

According to the review above, one may be inclined to assume that the metaphoric mapping of time and space in figurative speech reflects our mental space-time mapping. However, recent results cast doubt on this assumption (de la Fuente et al. 2014). Specifically, de la Fuente asked Morocccan Arabic speakers to perform a temporal diagram task (see Casasanto 2009). These speakers saw a cartoon character from above, with one box in front and another box behind this character. After the participants read, for example, the sentence "Mohammed went to visit a friend who liked plants and tomorrow he would be going to visit a friend who likes animals", they were told to write the initial letter A for animals in one box and P for plants in the other box. Arabic Moroccans tended to place the past event A more frequently in the front box and the future event P in the back box. The reverse result pattern was observed for a control group of Spanish participants. Therefore, de la Fuente et al. have concluded that Moroccan Arabic speakers in contrast to Spanish speakers tend to associate mentally the past with the front (and future with the back). Interestingly, however, the front-back time metaphors in the Arabic language are similar to those in most languages of the world with the future "ahead" and the past "behind". According to de la Fuente et al., this cross-cultural difference demonstrates that linguistic space-time metaphors need not reflect our spatial thinking about time. Furthermore, they propose the temporal-focus hypothesis, which holds that people tend to associate the past with the "front" to the extent that their culture encourages them to focus on the past (like their Moroccan Arabic speakers). In fact, they provide further convincing experimental evidence for this hypothesis. More research is certainly needed to examine the generality of this dissociation between language and thinking.

In summary, a robust space-time congruency effect manifested in the RT studies reviewed in this section. This effect is stable across different classes of stimuli and it has been documented for the sagittal and transversal mental timeline, although some studies could not replicate the effect for sagittal direction (Fuhrman et al. 2011; Walker et al. 2014). Nevertheless, the results concerning the sagittal mental timeline are consistent with linguistic data which imply that we use the back-front dimension of space when we talk about time. Moreover, the results concerning the transversal mental timeline provide evidence that the left–right dimension of space is also employed in the conceptualization of time, although this dimension is not used in natural languages to express time.

3. Linguistic relevance of the mental timeline

Although the above review shows that ample of evidence supports the notion that the mental timeline is psychologically real, its functional significance for the processing of time-related information has not been sufficiently addressed. Yet, it seems possible that humans and even primates as well as scrub jays rely on the mental timeline, when they mentally travel through time, for example, for planning future actions (Suddendorf and Corballis 2007, 2010). However, whether the mental timeline is also involved in comprehending natural language temporal expressions is still unclear. Some studies were designed to tackle this issue (Sell and Kaschak 2011; Ulrich et al. 2012; Ulrich and Maienborn 2010).

For example, Ulrich and Maienborn (2010) investigated whether sentence processing automatically activates the mental timeline, which is an unsettled issue (e.g., Santiago et al. 2007; Weger and Pratt 2008). They argue that the space-time congruency effect can be attributed to two alternative accounts. The first account attributes this effect to memory. Accordingly, people's memory access is facilitated when the mapping of past and future to the right and left is consistent with the direction of the mental timeline. By contrast, this access is hampered if this mapping is inconsistent with the direction of the mental timeline as in the incongruent condition. Therefore, this memory account entails faster responses in the congruent than in the incongruent condition.

According to the second account, the temporal reference of a sentence produces automatic response activation. In particular, temporal sentence information about the past automatically activates the left body space, whereas information related to the future activates the right body space. Such activation could be seen as analogous to the Simon effect (Simon and Rudell 1967) and the SNARC effect (Spatial Numerical Association of Response Codes; Dehaene, Bossini and Giraux 1993), in which task-irrelevant stimuli influence the speed of the response. For example, according to the view of embodied cognition, language understanding is grounded in bodily experiences (e.g. Barsalou 2008). Consistent with this notion, experimental work has documented that task-irrelevant non-temporal linguistic information can produce automatic response activation (e.g., Glenberg and Kaschak 2002; Lachmair, Dudschig, De Filippis, de la Vega, and Kaup 2011).

In order to distinguish between these two accounts, Ulrich and Maienborn (2010) designed an experiment analogous to the SNARC paradigm. In this experiment participants were asked to judge whether time-related sentences were sensible or not by pressing a left or a right key. Specifically, in each trial of their experiment participants judged the content of a sentence (i.e., sensible vs. nonsensical) but not its temporal relation to the past or the future. Therefore, the temporal information of the sentence was no longer task-relevant. Thus, if sentence meaning is action based (e.g., Glenberg and Kaschak 2002), 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 response movements on the right body side. Contrary to this prediction, no space–time congruency effect was observed in this experiment, a fact which argues against an automatic account. In other words, the results by Ulrich and Maienborn revealed that the space-time congruency effect emerges when temporal sentence information is task-relevant but not when this information is task-irrelevant. Therefore, this pattern of results suggests that the time-space congruency effect on the transversal axis observed in previous studies reflects a facilitated memory access instead of automatic sensorimotor activation.

The results of Ulrich and Maienborn (2010) reported above are at variance with the notion that the metaphoric mapping from space to time operates automatically at deeper levels of meaning representation. However, the failure to find an automatic activation in their experiment might be attributed to the fact that coding of time from left to right has no obvious counterpart in natural languages. Even though virtually all languages have explicit spatial means to refer to time, there seems to be no language that uses the concepts of 'left' and 'right' for the expression of time. For instance, although one frequently encounters expressions like *the day before Christmas* in the languages of the world, no case of an expression like **the day to the left of Christmas* has been certified (Haspelmath 1997; Radden 2004). Thus, in languages worldwide, there is a strong tendency towards the use of the back-front axis where the future is usually mapped onto the front and the past onto the back (see Haspelmath 1997; Radden 2004; Traugott 1978; and Núñez and Sweetser 2006, for a prominent case of reversed mapping).

If processing of temporal sentence information relies on the automatic activation of the back-front axis, a space-time congruency effect should therefore emerge even when the temporal content of the sentence is task-irrelevant. Consequently, Ulrich et al. (2012) assessed the linguistic relevance of the back-front mental timeline. They examined if temporal sentence information would automatically activate the metaphoric mapping from space to time for movements along the back-front axis. As in the experiment by Ulrich and Maienborn (2010), participants performed a sensicality judgment about the sentence content, whereas the temporal reference of a sentence was no longer a task-relevant dimension. However, instead of responding with the left or the right hand, participants were now asked to move a slider with their dominant hand from a center starting position toward the front or back. The slider was located in front of the participant and moved along the midsagittal plane. The RT results of this experiment replicated the results of the experiment by Ulrich and Maienborn (2010), that is, no space-time congruency effect was observed when the temporal content of the sentence was task-irrelevant.

Interestingly enough, a congruency effect was also absent when participants were asked to perform a secondary task in this sensicality paradigm to ensure that they explicitly attended to the temporal information of the sentence – an idea adapted from the dual-task procedure in Ouellet, Santiago, Funes, and Lupiáñez (2010).[3] More specifically, following the sensicality judgment the word *Vergangenheit?* ('past?') or *Zukunft?* ('future?') appeared on the screen in front of the participant. The participant was requested to press the space bar on the computer keyboard if the answer to this question was *yes* and to refrain from responding otherwise. Although this secondary task forced the participants to process the temporal content of each sentence, no space-time congruency effect could be observed in this sensicality experiment. Therefore, consistent with the previous conclusion concerning the functional relevance of the transversal timeline, the results reported by Ulrich et al. (2012) suggest that the sagittal timeline is not functionally involved in the processing of temporal sentence information.

Although the results reviewed so far suggest that the spatial left-right or back-front timeline is not automatically involved in processing the temporal meaning of a sentence, experimental results by Sell and Kaschak (2011) provide evidence for an automatic processing of temporal content in discourse. They have argued that an automatic activation of the mental timeline can only be observed at a behavioral level for sufficiently large time shifts in a multiple sentence story. They presented to participants small texts consisting of three sentences, in which the second sentence expressed a time shift either to the past or to the future such as in the following example:

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

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3. These authors reported a priming effect of words on the response speed in a subsequent spatial discrimination task. Importantly, they required the participants to keep the meaning of the prime in working memory, while performing the discrimination task. Therefore the secondary task in their study required semantic processing of the prime. This study is reviewed in more detail below.

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. In other words, RT was shorter when past (future) was mapped on responses toward (away from) the body. This effect disappeared, however, when the time shift was small (e.g., one day vs. one month) and when the responses were spatially arranged and required no arm movement (i.e., one response hand located on a key close to the body and the other one located on a key farther away from the body). Therefore, it seems likely that the mental timeline is required to build up a situation model because relative time is an important determinant in constructing such models (Zwaan and Rapp 2006). In order to comprehend the temporal relationship between single events conveyed by each single sentence, these events need to be placed into a chronological order along the timeline and integrated for discourse comprehension. In this case, a sufficiently large time shift during the discourse may well activate spatial schemata – for example, when one tries to mentally integrate the temporal sequence of events of a narrative text. To do so, participants may organize these events along a mental timeline, which, in turn, may activate spatial schemata. This does not mean, however, that the processing of a single sentence itself would automatically activate the front-back timeline. Future research is required to test this hypothesis – namely, that spatial schemata may be activated automatically during the buildup of a discourse model, but not during the processing of a single sentence.

The front-back congruency effect originally reported by Torralbo et al. (2006) for vocal responses may also be interpreted as evidence for an automatic activation of the sagittal timeline. As reviewed in the preceding section, participants viewed a face silhouette looking to the right or to the left. A time-related word appeared in front of or behind this face and participants responded vocally either *pasado* ("past") or *futuro* ("future"). RT of the response was shorter in congruent trials (e.g., a future-related word appeared in front of the face) than in incongruent trials (e.g., a future-related word appeared behind the face). Because the spatial relationship between the face and the word was task-irrelevant, the observed congruency effect in their first experiment is consistent with an automatic activation view of the back-front timeline.

Alternatively, this effect may be attributed to the linguistic nature of the vocal response, rather than to the linguistic stimulus that appeared before or behind the face silhouette. For example, the vocal responses *past* and *future* may activate spatial schemata rather than the temporal reference of the target word. Therefore, the front–back congruency effect obtained in their first experiment might be attributed to the temporal content of the vocal responses (similar to a Stroop effect), rather than to the temporal reference of the target words. This account receives support from the data of their second experiment with manual rather than vocal responses, because in this case the front–back congruency disappeared.

So far, there is no definite empirical support for the view that the processing of linguistic temporal information necessarily involves the mental timeline. Thus, one may ask whether automatic activation of the mental timeline can be documented at all when one has to process linguistic information, for example, such as a single time-related word (e.g., *tomorrow, yesterday*). At least four studies support this possibility (Kong and You 2012; Lakens, Semin, and Garrido 2011; Ouellet, Santiago, Funes, and Lupiáñez 2010; Rolke et al. 2013).

Lakens et al. (2011, Experiment 2) presented a single word binaurally via headphones. The word could either refer to the past or to the future, or had no time-related meaning (e.g. *paper*). The participants were asked to judge whether the word appeared louder on the left or on the right channel. Their psychophysical results show that past-related words tended to appear louder on the left than on the right channel. By contrast, future-related words appeared louder on the right than on the left channel. According to the authors, this surprising result shows that the meaning of temporal adverbs is grounded in concrete sensory domains (Barsalou 2008). Thus, this conclusion is consistent with the notion that temporal adverbs automatically activate the mental timeline.

A similar conclusion was reached by Ouellet, Santiago, Funes, et al. (2010). In a visual priming paradigm, they investigated whether the temporal reference (past or future) of a word in working memory orients visual attention (to the left or the right, respectively) and thus affects the speed of manual responses to a dot that appeared on the left or the right on a screen. Words were presented shortly before the appearance of the dot. After the dot localization task, participants were probed about the temporal reference of the word. The purpose of this secondary task was to ensure that participants paid attention to the temporal reference of the word. RT was shorter when a past-related word preceded a dot that appeared on the left compared to the right side. An analogous effect resulted for future-related words. Kong and You (2012) replicated this finding for the auditory modality. In an experiment analogous to the one by Ouellet and colleagues they presented time related words biaurally via headphones. After the presentation of the words participants were asked to detect a tone presented on the left or right side. RTs were again shorter when past-related words preceded tones on the left side and future-related words preceded tones on the right side. The results of these studies show that time-related words induce shifts of attention towards the primed side of the mental timeline.

Rolke et al. (2013) also employed temporal words as primes that preceded a colored patch. Participants performed speeded color discrimination requiring a response with their left or right hand. Although the visually presented prime word was not relevant for performing the color discrimination task, past-related primes facilitated response with the left hand and future-related primes with the right hand. This priming effect is consistent with the notion that the temporal content of a single word can automatically activate the mental timeline. However, this automatic priming effect was absent for auditory primes and only reappeared when auditory attention was directed toward the prime.

Priming experiments conducted in our own laboratory investigated whether preceding activation of spatial concepts automatically influences the processing of temporal linguistic information. Thus, in contrast to the previous studies our priming experiments examined whether spatial primes affect the processing of time-related words. In a first experiment, the lexical decision paradigm of de Groot, Thomassen, and Hudson (1986) was adapted to address this issue. In each trial of the experiment, a spatial prime (a tone presented to the left or to the right side of the participant) preceded a letter string, which was either a time-related word or a pseudoword. Participants were asked to make a speeded key press with their dominant hand if the string was a word and to refrain from responding in case of a pseudoword (Go/NoGo task). We conjectured that if the task-irrelevant spatial information conveyed by the auditory prime influences the processing of temporal linguistic information, a space-time congruency effect should emerge. It was expected that priming the left side leads to faster responses to past-related words and priming the right side leads to faster responses to future-related words. However, no such priming effect emerged.

This observation was replicated in two further priming experiments (Eikmeier and Ulrich 2012a, 2012b). In one experiment, a choice RT task was employed instead of a Go/NoGo task. Participants were asked to respond to words with a left (right) key press and to pseudo-words with a right (left) key press. No space-time congruency effect was observed. In a third experiment, instead of tones arrows pointing to the left or to the right were used as primes. Again, no space-time congruency effect was obtained. Although semantic priming effects are commonly observed for word primes (Balota, Yap, and Cortese 2006) and similar effects have been documented for the mental timeline (Lakens et al. 2011; Ouellet, Santiago, Funes, et al. 2010; Rolke et al. 2013), no effect of spatial primes on word processing was observed in our studies. In conclusion, the results of our priming experiments suggest that activation of spatial concepts does not influence the processing of time-related linguistic information irrespective of priming and response type.

4. Conclusion

The present review clearly shows that the mental timeline is psychologically real. The existence of this mental timeline has been experimentally demonstrated with various methodological approaches ranging from sorting tasks (e.g. Tversky et al. 1991) to RT tasks (e.g. Torralbo et al. 2006). These studies have investigated the sagittal as well as the transversal mental timeline. Although the directionality of these timelines is determined by cultural background (see Núñez and Cooperrider 2013), they can be found in almost all cultures. These results are clearly in agreement with the notion that people use spatial concepts when they think about time (Boroditsky 2000; Casasanto and Boroditsky 2008; Clark 1973). Although spatial terms in natural languages are commonly used to express temporal notions, the cognitive function of the mental timeline for natural language understanding is still unsettled.

As discussed above, it should be the case that if the mental timeline is functionally involved in the comprehension of temporal expressions, these expressions should automatically activate this timeline. This hypothesis was motivated by previous work documenting that task-irrelevant non-temporal linguistic information can produce automatic response activation (e.g. Glenberg and Kaschak 2002). However, the work reviewed in this section reveals that the evidence concerning this hypothesis is rather mixed. Some studies report support for this hypothesis concerning the processing of temporal information at the word level. For example, temporal word primes seem to produce automatic activation. By contrast, spatial primes seem not to affect the processing of temporal words (Eikmeier and Ulrich 2012a, 2012b). On the sentence level however, only negative evidence for automatic activation of the mental timeline has been reported so far (Ulrich et al. 2012; Ulrich and Maienborn 2010). Finally, on the discourse level, positive as well as negative evidence has been reported for the functional involvement of the sagittal mental timeline (Sell and Kaschak 2011). Positive evidence has only been reported when the task required arm movements but not for discrete keypresses. Therefore it seems likely that the linguistic level (word, sentence or discourse) at which temporal information is processed plays a crucial role whether or not the mental timeline becomes functionally engaged.

It is obvious from this review that to date a definite assessment of the functional significance of the mental timeline is not possible. Prospective research is needed that clarifies more systematically the conditions under which automatic activation of the mental timeline occurs. As a first step, future studies need to evaluate the automatic activation hypothesis within the same experimental paradigm for words, sentences, and discourse material. Only then it is possible to assess whether the activation of the mental timeline depends on the level of linguistic structure as the present review suggests.

In order to gain a comprehensive picture of the psycholinguistic relevance of the mental timeline, we strongly believe that null effects in experiments with high statistical power are also of theoretical importance to advance the understanding of the functional role of the mental timeline. Such effects can clearly demonstrate the limits of the tasks conforming to the predictions of the automatic activation hypothesis. This is especially true if experiments employ a design analogous to the one that has produced clear RT effects for a related issue in previous research. Not publishing such null effects will greatly bias the research (i.e., file drawer problem, Rosenthal 1979) and create the exaggerated view that the effects reported in the literature are ubiquitous phenomena attesting a functional significance of the mental timeline (see Fiedler 2011; Simonsohn, Nelson, and Simmons 2014). In addition, plain replications of studies reporting positive effects are desirable to reveal false positive results, because it is reasonable that more than 50% of the significant results are actually false positive (Pashler and Harris 2012).

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