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BRIEF REPORT

Dimensional overlap between time and space

Verena Eikmeier · Hannes Schröter · Claudia Maienborn · Simone Alex-Ruf · Rolf Ulrich

Abstract Several pieces of evidence suggest that our mental representations of time and space are linked. However, the extent of this linkage between the two domains has not yet been assessed. We present the results of two experiments that draw on the predictions of the dimensional overlap model (Kornblum, Hasbroucq, & Osman, Psychological Review 97:253–270, 1990). The stimulus and response sets in these reaction time experiments were related to either time or space. The obtained stimulus–response congruency effects were of about the same size for identical stimulus–response sets (time–time or space–space) and for different stimulus–response sets (time–space or space–time). These results support the view that our representations of time and space are strongly linked.

Keywords Spatial representation of time · Dimensional overlap model · Space–time congruency effect

Time is a fundamental component of our cognition. Although time is ubiquitous in our thinking, it is associated with no specific sensory organ (Grondin 2001; Woodrow 1951). Therefore, the question of how time enters into our thinking and shapes our cognition has challenged philosophers and cognitive scientists (Evans 2005; Le Poidevin 2004; Roeckelein 2000). It appears that we mentally draw on the more accessible domain of space when we are thinking about the abstract concept of time (e.g., Boroditsky 2000; Boroditsky and Ramscar 2002; Casasanto et al. 2010; Núñez and Sweetser 2006; Torralbo et al. 2006; for a review, see Santiago et al. 2011). For example, this space–time linkage is reflected by the fact that languages around the world use spatial expressions to talk about time (e.g., *back in the old days* or *to be ahead of one's time*; Clark 1973; Haspelmath 1997). Thus, linguistic data suggest that our cognitive representation of time is connected to our representation of space (e.g., Boroditsky 2000).

V. Eikmeier · H. Schröter · C. Maienborn · S. Alex-Ruf · R. Ulrich
University of Tübingen, Tübingen, Germany

V. Eikmeier (✉)
Department of Psychology, University of Tübingen,
Schleichstraße 4, 72076 Tübingen, Germany
e-mail: verena.eikmeier@uni-tuebingen.de

Experimental evidence also supports this assumption. For example, Boroditsky (2000) demonstrated that spatial primes indicating either a spatial backward or forward movement do affect whether participants judge ambiguous temporal information (e.g., "Next Wednesday's meeting has been moved forward two days")[1] as pointing backward or forward in time. In addition, Torralbo et al. (2006) provided the first evidence of a space–time congruency effect on reaction times (RTs). Specifically, these authors asked participants to respond to the temporal content of a word with a left or a right keypress. Participants tended to respond faster to past-related (future-related) words with a left (a right) keypress. This space–time congruency effect has been replicated under various conditions (e.g., Santiago et al. 2007; Ulrich and Maienborn 2010; Weger and Pratt 2008) and observed for back–front mappings of past and future, as well (e.g., Hartmann and Mast 2012; Sell and Kaschak 2011; Torralbo et al. 2006; Ulrich et al. 2012). Furthermore, the influence of spatial information on temporal judgments is stronger than the influence of temporal information on spatial judgments (for which there usually is no effect at all), suggesting an asymmetrical dependency of time and space (Casasanto and Boroditsky 2008; Casasanto et al. 2010).

Although research has documented that our thinking about time is affected by spatial information, it is still unclear how strongly our cognitive representation of time is connected to our representation of space. On the one hand, it has been argued that our representations of time and space share a common metric system (e.g., Bueti and Walsh 2009; Walsh

[1] This prominent sentence was originally introduced by McGlone and Harding (1998).

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2003). This view implicates a rather close relationship of time and space. On the other hand, one may argue that time and space—despite sharing a similar structure—are not based on a common metric system (Murphy 1996). The latter notion is supported, for example, by neuropsychological data from patients that have shown that spatial and temporal meanings of prepositions can be impaired independently (Kemmerer 2005). Finally, it is possible that the domains of time and space are weakly linked. For example, the domain of space may be required to structure the domain of time (e.g., Boroditsky 2000). After this structure has been established, however, thinking about time no longer functionally relies upon the dimension of space. But nevertheless, it may still be influenced by spatial information.

The present experiments were designed to reveal the degree of dependency of time on space by using a novel approach that draws on predictions made by the dimensional overlap model (Kornblum et al. 1990). This model was originally developed to explain different types of stimulus–response congruency (SRC) effects in RT research and has become a prominent model in this field (e.g., Liu et al. 2010; Shiu and Kornblum 1999; Tlauka 2005; Wascher et al. 1999). The model holds that the degree of dimensional overlap between stimulus and response sets depends on two key features (see Kornblum et al. 1990, p. 258): First, the overlap increases with the amount of similarity between the two sets, and second, it also increases with greater homomorphical mapping between elements of the two sets. The degree of dimensional overlap determines the size of SRC effects; thus, a strong dimensional overlap of the stimulus and response sets should result in a large SRC effect.

According to the logic of the dimensional overlap model, the space–time congruency effect occurs because of the dimensional overlap between time-related stimuli and space-related responses. Consequently, the size of the space–time congruency depends on the degree of overlap between time and space. The present experiments were designed to reveal the strength of this time–space linkage. In particular, we are comparing the size of the SRC effect in two conditions. In the experimental condition, the stimulus and response sets came from different domains (e.g., time-related stimuli and space-related responses). In the control condition, the two sets came from the same domain (e.g., time-related stimuli and time-related responses). If the dimension of time is strongly connected to the dimension of space, the SRC effects in the experimental condition and the control condition should be of about the same size. If, however, time is only weakly linked to space, the SRC effect should be smaller in the experimental than in the control condition. In Experiment 1, we employed a time-related stimulus set and a space-related response set in the experimental condition, whereas in the control condition, both sets were time-related. For Experiment 2, we used a space-related stimulus set and a time-related response set in the experimental condition, whereas in the control condition, both sets were space-related.

Experiment 1: Temporal stimuli

Method

Participants A group of 40 volunteers (12 male, 28 female; mean age=24.8 years, *SD*=7.4 years; one left-handed, all with normal or corrected hearing and vision) participated in this experiment. All were native speakers of German and naïve with respect to the experimental hypothesis. One-half of the participants performed in the experimental condition, and the second half in the control condition. Four additional participants were tested, but their data were excluded from the analysis due to high error rates (>10 % errors).

Apparatus and stimuli The experiment took place in a sound-attenuated room. Time-related sentences were displayed in black font against a white background in the center of a computer screen at a viewing distance of 80 cm. The same set of sentences described in Ulrich and Maienborn (2010) was used. It consisted of 60 sensible sentences referring to the past (SP), 60 sensible sentences referring to the future (SF), 60 nonsensical sentences referring to the past (NP), and 60 nonsensical sentences that referred to the future (NF). Table 1 shows examples for each sentence type. Vocal RTs were registered with a headset microphone, and the responses were checked online by the experimenter.

Procedure and design Each trial started with the presentation of a fixation cross for 200 ms. Following an interstimulus

Table 1 Example sentences used in Experiment 1 and their English translations

Sentence Type	Examples
Sensible past-related (SP)	*Hanna reparierte gestern das Fahrrad.* “Yesterday, Hanna repaired the bike.”
Sensible future-related (SF)	*Morgen früh unterschreibt der Chef den Antrag.* “The boss will sign the application tomorrow morning.”
Nonsensical past-related (NP)	*Die Tannen haben sich badend ihren Mantel angezogen.* “The fir trees have put on their coat while bathing.”
Nonsensical future-related (NF)	*Nächsten Sonntag wird das Rathaus die Erbse heiraten.* “Next Sunday, the town-hall will marry the pea.”

interval of 500 ms, a sentence was presented for a maximum of 4,000 ms or until a response was registered. The sentences of the SP, SF, NP, and NF sets were presented in random order, and each sentence was presented only once in each congruency condition (see below). The participants were instructed to refrain from responding to nonsensical sentences (no-go trials). These no-go trials were employed to make sure that participants processed the content of the sentences thoroughly. For sensible sentences, participants were asked to indicate whether the sentences referred to the past or the future. The experimental group responded with the word *vorne* (German for "in front") or *hinten* ("behind"), whereas the control group responded with the word *Vergangenheit* ("past") or *Zukunft* ("future"). Error feedback was provided by a tone (440 Hz, 500 ms) when a wrong response was given (including any response to nonsensical sentences). After 2,000 ms, the next trial was initiated.

For each group of participants, the experiment consisted of two congruency conditions. Each condition was blocked and comprised 240 trials. In addition, eight practice trials were presented at the beginning of each block. In the congruent condition, participants of the control group were asked to respond with *Zukunft* ("future") to SF sentences and with *Vergangenheit* ("past") to SP sentences. In the incongruent condition, this S–R assignment was reversed. An analogous procedure was applied to the experimental group. Thus, in the congruent condition, these participants responded with *vorne* ("in front") to SF sentences and with *hinten* ("behind") to SP sentences. In the incongruent condition, this S–R mapping was reversed. The order of the two congruency conditions was balanced across participants within each group. The design of this experiment was Group (experimental vs. control)×Congruency (congruent vs. incongruent).

Results and discussion

The rate of false alarms to nonsensical sentences was low (3 %). Trials with RTs >4 s (less than 1 % of all responses) were considered outliers and excluded from the RT analysis. The upper part of Fig. 1 depicts the mean RTs for responses to sensible sentences for the two congruency conditions and for each group. An analysis of variance (ANOVA) on RTs revealed a main effect of congruency. As one expects, the mean RT was longer for the incongruent (2,310 ms) than for the congruent (2,123 ms) condition, $F(1, 38)=14.4$, $p<.001$, $\eta_p^2=.28$. Most importantly, this effect was not significantly modulated by group, $F(1, 38)=2.1$, $p=.16$, $\eta_p^2=.05$. Error rates for responses to sensible sentences are depicted at the bottom of Fig. 1. The overall error rate was relatively low (8 %). An ANOVA on error rates revealed a main effect of congruency, $F(1, 38)=26.2$, $p<.001$, $\eta_p^2=.49$. The mean error rate was lower for the congruent (5 %) than for the

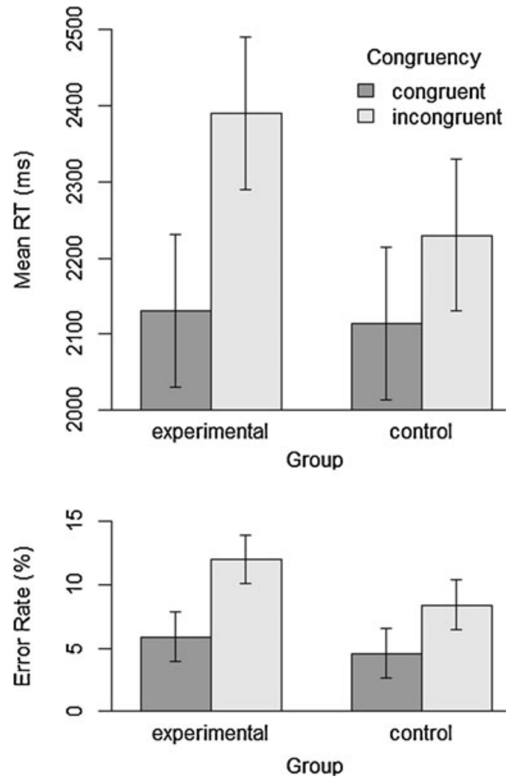

Fig. 1 Experiment 1: Mean reaction times (RTs, upper panel) and error rates (lower panel) as a function of group and congruency. Confidence intervals were computed as recommended by Masson and Loftus (2003)

incongruent (10 %) condition. As for RTs, the congruency effect was not significantly influenced by group, $F(1, 38)=1.4$, $p=.25$, $\eta_p^2=.04$. In this experiment, the SRC effect for time-related stimuli was independent of whether the responses were time-related or space-related. Therefore, the results suggest that the dimensions of time and space are strongly related. In Experiment 2, we assessed whether this result would also be observed for space-related stimuli.

Experiment 2: Spatial stimuli

Method

Participants A fresh sample of 40 volunteers (11 male, 29 female; mean age=22.7 years, *SD*=3.3 years; five left-handed, all with normal hearing and vision) participated in this experiment. They were all native speakers of German and naïve with respect to the experimental hypothesis. The data of one additional participant were excluded from the analysis due to a high error rate (>10 % errors). As in Experiment 1, half of the participants performed in the experimental condition, and the other half in the control condition.

Apparatus and stimuli The same apparatus and stimulus were used as in Experiment 1, except for the following changes. Instead of responding to sentences, participants were asked to respond to the location of a tone (440 Hz, 100 ms). This tone was presented either by a speaker in front of the participant or by a speaker behind the participant (distance to the participant: 80 cm).

Procedure and design Instead of a sentence, the tone was presented; its location was randomized across trials. The control group responded with the word *vorne* ("in front") or *hinten* ("behind"), whereas the experimental group responded with the word *Vergangenheit* ("past") or *Zukunft* ("future"). As in Experiment 1, each group of participants was tested in two congruency conditions. Each condition was blocked and comprised 120 trials. In addition, eight practice trials were presented at the beginning of each block. In the congruent condition, the control group was asked to respond with *vorne* ("in front") if they perceived the tone as originating from the front speaker, and with *hinten* ("behind") if they perceived the tone as originating from the back speaker. This S–R assignment was reversed in the incongruent condition. An analogous procedure applied to the experimental group. Thus, the design was identical to that of Experiment 1: Group (experimental vs. control) × Congruency (congruent vs. incongruent).

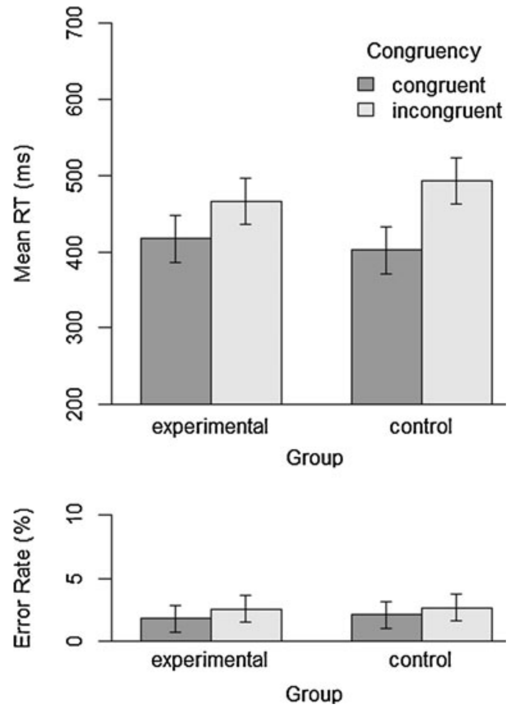

Fig. 2 Experiment 2: Mean reaction times (RTs, upper panel) and error rates (lower panel) as a function of group and congruency. Confidence intervals were computed as recommended by Masson and Loftus (2003)

Results and discussion

As in Experiment 1, trials with RTs >4 s (less than 1 % of all responses) were considered outliers and excluded from the RT analysis. The upper part of Fig. 2 shows mean RTs as a function of congruency condition and group.

An ANOVA on RTs revealed a significant effect of congruency, $F(1, 38)=21.7, p<.001, \eta_p^2=.36$. As in Experiment 1, the mean RT was longer for the incongruent (480 ms) than for the congruent (409 ms) condition. Crucially, this effect again was not significantly modulated by group, $F(1, 38)=2.0, p=.17, \eta_p^2=.05$. The overall error rate was low (2 %), and an ANOVA showed no significant main effects or interactions in the error data (lower part of Fig. 2). In this experiment, the SRC effect for spatial stimuli was independent of whether the responses were also space-related or were time-related. The results of this experiment are consistent with the findings from Experiment 1 and suggest again that the dimensions of time and space are strongly related.

General discussion

There is broad evidence that our cognitive representation of time is connected to our representation of space (e.g., Boroditsky 2000; Santiago et al. 2011; Walsh 2003). In the present study, we aimed to assess the strength of this time–space linkage. The logic of the present RT experiments draws on the predictions of the dimensional overlap model (Kornblum et al. 1990). As we discussed in the introduction, this model postulates that the size of S–R congruency effects depends on the dimensional overlap between the stimulus and response sets. In the present RT experiments, the stimulus sets were either time-related (sentences referring to the past or the future) or space-related (tones from in front of or behind a participant). Likewise, the response sets in these experiments were either time-related (vocal responses referring to time; i.e., "past" or "future") or space-related (vocal responses referring to space; i.e., "front" or "back"). The dimensional overlap of the two sets was maximal for the control groups (S–R: time–time or space–space). Thus, we expected large SRC effects for these groups, and these effects served as a benchmark to assess the size of the SRC effects for the experimental groups (S–R: time–space or space–time). If time and space are strongly connected, the SRC effects for the experimental and control groups should be of comparable sizes. If, however, time and space are weakly linked, the SRC effects should be smaller for the experimental groups.

In Experiment 1, we observed large SRC effects on RTs for both the experimental (time–space) and the control (time–time) group, with the effect being somewhat smaller for the latter group. In Experiment 2, we again obtained a meaningful SRC effect for both the experimental (space–

time) and the control (space–space) group. This time, however, the effect was numerically larger in the latter group. Because the SRC effects were of comparable sizes in the control and experimental groups for both experiments, this pattern of results clearly supports the notion that the dimensions of time and space are tightly connected.

The present results are consistent with the notion that our representations of time and space share a common metric system (Walsh 2003) and that this metric interacts with action (Bueti and Walsh 2009; Ishihara et al. 2008). In fact, studies with children and animals (Church and Meck 1984; Gallistel and Gibbon 2000), as well as neuropsychological data (Basso et al. 1996), have indicated that space, time, and quantity are processed within shared neuronal networks. As was argued by Casasanto et al. (2010), this theory of magnitude (ATOM; Walsh 2003) implicitly assumes that space and time are symmetrically related. Contrary to this implicit assumption, the results of several behavioral studies support an asymmetric dependence (e.g., Casasanto and Boroditsky 2008; Casasanto et al. 2010). For example, the perceived presentation time of a line increases with its physical length. By contrast, perceived line length is independent of presentation time (Casasanto and Boroditsky 2008). Although our results are agnostic with regard to the direction of the dependency between time and space, they nevertheless provide information about possible relationships between our representations of the time and space dimensions. One possibility is that our representations of time and space do not overlap in the sense of an intersection, but that our representation of time is embedded in our representation of space. Such an embedded view would be consistent with the notion of an asymmetrical relation between time and space. It would also be consistent with the notion that time and space share common neural networks, and would be in line with the results of the present experiments.

An alternative possibility is that the representations of time and space overlap because they both draw on an identical cognitive structure. The assumption of such a representational overlap is an inherent feature of, for example, the framework of common coding (Prinz 1990, 2012). This framework proceeds from the premise that compatibility effects are grounded on representational overlap—that is, on the linkage of perception-related and action-related codes. Interference effects occur if naturally linked codes are forced into an incompatible mapping by experimental instructions. Within this framework, interference should emerge when, for example, a future-related stimulus is mapped onto a back-related response. Therefore, this framework could also account for the present pattern of results. Because the SRC effects observed in the present study were of comparable sizes in the control and experimental groups, the structure of the time-related and space-related codes seem to be virtually interchangeable. This framework, however, is silent with respect to the directional dependency between space and time.

The present results seem to be incompatible, however, with the notion that time is weakly linked to the domain of space (Boroditsky 2000). Such an account would predict a larger SRC effect when the stimuli and responses share the identical domain (time–time, space–space) rather than different domains (time–space, space–time). In addition, the present data are also at variance with the structural-similarity view (Murphy 1996), which holds that all domains are represented separately, even when they are structurally similar.

In this study, we employed a novel approach to assess the strength of the linkage between time and space. This approach drew on the predictions of the dimensional overlap model and assessed how strongly representations from the different domains overlap or are linked to each other. The results suggest that the domains of time and space are strongly related, rather than being weakly linked, or even separately represented.

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