Walking back to the future: The impact of walking backward and forward on spatial and temporal concepts

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Abstract

Embodied cognition frameworks suggest a direct link between sensorimotor experience and cognitive representations of concepts (Shapiro, 2011). We examined whether this holds also true for concepts that cannot be directly perceived with the sensorimotor system (i.e., temporal concepts). To test this, participants learned object–space (Exp. 1) or object–time (Exp. 2) associations. Afterwards, participants were asked to assign the objects to their location in space/time meanwhile they walked backward, forward, or stood on a treadmill. We hypothesized that walking backward should facilitate the on-line processing of ”behind”/“past”-related stimuli, but hinder the processing of “ahead”/“future”-related stimuli, and a reversed effect for forward walking. Indeed, “ahead”- and “future”-related stimuli were processed slower during backward walking. During forward walking and standing, stimuli were processed equally fast. The results provide partial evidence for the activation of specific spatial and temporal concepts by whole-body movements and are discussed in the context of movement familiarity.

1. Introduction

Embodied cognition approaches suggest constitutional associations between cognitive processes and concrete sensorimotor experience (Shapiro, 2011). In general, embodied cognition approaches (for an overview see Fischer & Coello, 2016) assume that cognitive processes are composed not exclusively in the brain, but include the body and its sensorimotor processes. For instance, embodied cognition approaches build on the idea that concepts (= people's representations of categories, e.g.: apple, house) develop from aggregating information from perception, action, and internal states (Barsalou, 2016). It follows that when investigating the concept of an apple, it is not sufficient to examine the cognitive processes and amodal information about apples – but it is also necessary to take into account the sensorimotor experience with apples. From an embodied cognition perspective, these sensorimotor processes form our concepts in a substantial way. As a consequence, a concept becomes reactivated when an associated sensorimotor or cognitive aspect of the concept is active (e.g. executing a movement as if biting into an apple). Over the last decades, many researchers explored the relationship between sensorimotor processes and concrete concepts (e.g., Barsalou, 2008; Kalénine, Bonthoux, & Borghi, 2009; Martin, 2007; Stanfield & Zwaan, 2001; for an overview, see Meteyard, Cuadrado, Bahrami, & Vigliocco, 2012). Although empirical evidence for links between actions and representations of *concrete* concepts has been well established, the critical next step for establishing an embodied approach of cognition would be to explore whether *abstract* concepts are embodied as well (for initial empirical evidence, see Casasanto & Dijkstra, 2010; Dijkstra, Eerland, Zijlmans, & Post, 2014). In this paper we refer to concrete concepts as concepts that are directly perceivable with our sensorimotor system such as 'apple' (Thill & Twomey, 2016), and to abstract concepts that are not directly perceivable with our sensorimotor system such as 'axiom' (i.e., concepts related to, for example, language processing, Buccino, Colagè, Gobbi, & Bonaccorso, 2016, and number processing, Marghetis & Youngstrom, 2014). In the present experiments we examined if and how movements influence the processing of two concepts that share a common mapping (Walsh, 2003), but differ in their degree of abstractness or sensorimotor perceivability (Kranjec, 2006): spatial concepts and temporal concepts.

Research focusing on the relationship between spatial and temporal concepts suggests a close connection between both concepts. The theoretical basis for most of the studies is the conceptual metaphor theory (Lakoff & Johnson, 1980), which states that abstract domains are understood in terms of other, more concrete domains. This relationship between space and time is among other things reflected in our language: When we talk about time, we use spatial terms (e.g., "The weekend is ahead of me"). The close connection between space and time has been shown in language studies (e.g., Boroditsky, 2000; Casasanto & Boroditsky, 2008; Casasanto et al., 2010), as well as in language-free paradigms (e.g., Casasanto & Boroditsky, 2008; Homma & Ashida, 2015).

Besides studies with healthy participants, further evidence for a close connection between spatial and temporal representations stems from research with patients suffering from neurological diseases (e.g., Saj, Fuhrman, Vuilleumier, & Boroditsky, 2013). For instance, in neglect patients Saj et al. (2013) examined if the ability to represent space is necessary for representing events along a mental time line. As neglect patients are not aware of their left side, and the left side is (in western cultures) associated with the past (Boroditsky, 2001), it was hypothesized that neglect patients would also be impaired in the processing of past-related stimuli. To address this, Saj et al. (2013) invited patients with neglect, patients with a stroke but without neglect symptoms, and healthy controls. Participants were first asked to associate and memorize objects with either the future or the past (e.g., apple – past). Notably, the stimuli were not inherently associated with the future or the past, but an association with the future or the past was built in a learning phase. In the following test phase, participants were then asked to recall and recognize the previously associated objects. Results showed that patients with neglect assigned more past-related items as being future-related than the other two groups, providing evidence for the automatic mapping of time on space (past – left, future – right). In sum, studies from different areas such as language processing (e.g., Eikmeier, Schröter, Maienborn, Alex-Ruf, & Ulrich, 2013; Matlock, Ramscar, & Boroditsky, 2005), gesture generation (e.g., Walker & Cooperrider, 2015) or child development (e.g., Casasanto, Fotakopoulou, & Boroditsky, 2010) provide evidence for a strong connection between concrete spatial and abstract temporal concepts, supporting the main tenets of the conceptual metaphor theory (Lakoff & Johnson, 1980) that abstract temporal concepts are based on more concrete spatial concepts.

Despite accumulating evidence showing that abstract temporal concepts are grounded in more concrete spatial concepts, the critical question remains to be answered: Do concrete movements influence related spatial and temporal concepts? Based on the conceptual metaphor theory as well as embodied cognition accounts, the prediction would be yes. The theoretical argumentation is that spatial concepts emerge by moving in and interacting with the spatial environment and that temporal concepts are therefore built on spatial concepts. Consequently, movements should influence the processing of spatial concepts and the processing of temporal concepts.

The empirical literature addressing either one of the concepts might provide hints on the nature of the complex relationship of both concepts. To start with the relationship between movements and *spatial* concepts, Tower-Richardi, Brunyé, Gagnon, Mahoney, and Taylor (2012) exemplarily examined if abstract concepts modulate the trajectories of hand movements. The authors combined abstract spatial primes (e.g., NORTH) with concrete spatial targets (UP) and tested whether these primes influenced participants' hand trajectories towards the according spatial location. Results indicated the manifestation of spatial concepts in movements in form of biased movement trajectories in incongruent trials (e.g., NORTH – LEFT). Further evidence suggests that these effects are not bound to spatial location tasks (Tower-Richardi et al., 2012), as the same pattern has been shown for spatial perspective-taking tasks (Tversky & Hard, 2009), and tasks that measure language-space associations (Dudschig, de la Vega, & Kaup, 2015).

There is also first evidence for a relation between movements and *temporal* concepts. An influence of passive whole-body movements on temporal concepts was shown by Hartmann and Mast (2012). Participants sat in an apparatus that moved them either forward or backward, meanwhile they were asked to respond to time-related stimuli (e.g. World War II, holidays on Mars). Results showed that future-related words were processed faster during forward movement than during backward movement, thereby providing evidence for an influence of passive whole-body movement on temporal concepts. Supporting evidence stems from studies indicating an influence of active movement on time-related stimuli (Dijkstra, Kaschak, & Zwaan, 2007) as well as an influence of time-related stimuli on (eye)movements (Martarelli, Mast, & Hartmann, 2016, Miles, Nind, & Macrae, 2010, Rinaldi, Locati, Parolin, Bernardi, & Girelli, 2016, but see also Stins, Habets, Jongeling, & Cañal-Bruland, 2016). Despite first evidence for an impact of movement on temporal representations (and vice versa), strong conclusions cannot be drawn based on the paucity of research on this matter.

To summarize, albeit strong evidence in the literature for a close connection between movements and spatial concepts (e.g., Dudschig et al., 2015; Tower-Richardi et al., 2012; Tversky & Hard, 2009), and first evidence for a connection between movements and temporal concepts (e.g., Dijkstra et al., 2007; Hartmann & Mast, 2012), combining investigations that integrate and differentiate the effects are lacking. Therefore, the purpose of the present paper is to address this gap by investigating both, the influence of walking forward and backward on spatial concepts as well as on temporal concepts. To keep the perception of optic flow constant and examine only the effects of proprioceptive information of the walking movement, participants walked on a treadmill.

One difficulty when comparing how directional movements prime specific spatial and temporal concepts is that spatial and temporal stimuli inherently differ in their sensory features, which is a confounding factor when comparing response times (Myers & DeWall, 2015). For example, if the temporal stimuli are per se less salient than the spatial stimuli, a valid comparison between temporal and spatial stimuli might not be possible. In the present experiment this problem is solved by applying an experimental design that allows a direct comparison between the influence of movements on spatial and temporal concepts: The stimuli are the same in both experiments, and only the corresponding association (either spatial: “10 meter behind you/ahead of you”, or temporal: “10 years in the past/future”) differs (inspired by Saj et al., 2013).

Here we examined, based on the basic assumption of conceptual metaphor theory (Lakoff & Johnson, 1980) and embodied cognition approaches (e.g., Shapiro, 2011), if movements influence the processing of spatial and temporal concepts. If movements influence our cognitive processing of time, on a theoretical level this would affirm the assumption that sensorimotor processes influence the cognitive processing of abstract concepts. On a practical level, it may then be possible to manipulate thinking about the future/past by means of modal primes: For instance, walking forward might be supportive if we plan a future project, or walking backward might help to remember something that happened in the past.

Our research questions were if specific *spatial* (Experiment 1) and *temporal* (Experiment 2) representations are activated when executing a directional whole-body movement. Given previous research on congruency effects between real movement direction and abstract spatial representations, we hypothesized that walking backward should facilitate the on-line processing (= to be remembered faster and with fewer errors) of "behind"- and "past"-related stimuli, but hinder the processing of "ahead"- and "future"-related stimuli, and a reversed effect for forward walking.

2. Experiment 1

In Experiment 1, we examined the influence of walking on spatial concepts. In an encoding phase, participants learned object-space associations (e.g., apple – behind). In a following recognition-test phase participants had to vocally assign objects to a previously learned location (behind, ahead) while performing a whole-body movement condition. The procedure of encoding- and recognition-test phase was repeated three times, with three different movement conditions (walking forward, walking backward, or standing on a treadmill).

2.1 Method

2.1.1 Participants.

A priori Gpower analysis for the analysis of response times, with an estimated effect size of $f = .25$ (assuming a small effect of the first within-factor Condition of $\eta = .03$ and adjusting the f-value by integrating the second within-factor Response; Rasch, Friese, Hofmann, & Naumann, 2014), an alpha = .05 and a recommended power = 0.8 (Cohen, 1988) revealed a required sample size of $N = 28$.

All participants were included in the analysis of response accuracy. For the analysis of response times, some participants did not reach the established threshold, meaning more than five correct answers per Response ("ahead", "behind") and Condition (forward, backward, standing), which resulted in a relatively high drop-out rate. To ensure data quality for the analysis of the response times, we decided to invite more participants into the lab, until the required sample size would be achieved.

The total sample was therefore 57 participants (37 female), whereas 28 had to be excluded from the analysis of response times due to failure to comply with task performance required. The mean age of the participants was 22.7 years (*SD* = 3.2). Primary inclusion criteria for the participants were no health restrictions with regard to their walking abilities (for security reasons in the backward condition) and age between 18 and 65.

All participants provided informed consent and were free to withdraw from testing at any time. The experiment was approved by the ethical committee of the local institution.

2.1.2 Apparatus and Stimulus.

The idea for the instruction and the stimuli was taken from Saj et al. (2013) with some important adaptations for the experimental examination of the present research question: 1) The perspective was changed from a third-person perspective to an egocentric perspective, due to the fact that the walking manipulation also occurred from an egocentric perspective. 2) The stimuli were presented auditorily, in the encoding phase as well as in the recognition-test phase (see Appendix A, Table 1; 20 foods, 20 clothes, 20 furniture[1]). For this purpose, 60 objects with an equal number of letters were recorded and edited in a way that all stimuli were equally long (666 ms). The method of presenting the stimuli auditorily and recording vocally produced answers had the advantage that any reference to a spatial relation (e.g. when lifting the arm or moving the finger to press a button) was omitted.

The stimuli were presented via a wireless headset (Sennheiser MB Pro 2UC). The experiment was run using Inquisit software (http://millisecond.com) and the speech recognition was done using the Inquisit speech recognition engine. The targets of interest were presented on-line, in real-time during body motion, meanwhile participants kept walking forward or backward (or standing) with a speed of 3 km/h (normal walking speed, examined during pilot work) on a standard treadmill.

The Vividness of Mental Imagery Questionnaire (VVIQ2; Marks, 1995) was completed by the participants after the experiment, because high visualizers have been shown to be superior in short-term recall of concrete as well as abstract words (McKelvie & Demers, 1979). Further, a sociodemographic questionnaire, including relevant sociodemographic

[1] Example sound files can be accessed at https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/FYJ6YT

questions, was administered using SoSci Survey (Leiner, 2015) and completed by the participants.

2.1.3 Procedure.

All participants completed three blocks (within-subject design, latin square randomized order of conditions). Each block contained an encoding phase, followed by a recognition-test phase. The order of the trials was completely randomized, as well as the assignment to a location in space. At the beginning of the experiment, participants put on headphones and followed instructions on the screen. Before starting with the first encoding phase, participants completed five pre-learning trials to learn the meaning of two symbols: one symbol for ahead (*) and one symbol for behind (°). One of the two symbols was presented on the screen and participants indicated verbally if this symbol represented ahead ("vorne") or behind ("hinten"). Participants received feedback (correct or not correct response).

Encoding phase During the encoding phase participants were instructed as follows (translated from German, and adopted from Saj et al., 2013):

"Imagine that certain food is located either 10 meter behind you or 10 meter ahead of you. In the following, you will learn which food is located behind and which food is located ahead of you. Food that is located behind you is indicated with a (°), food that is located ahead of you is indicated with a (*)."

The 20 items were then presented auditorily one at a time, in a randomized order, 10 of them accompanied with the symbol for "ahead" and 10 of them accompanied with the symbol for "behind". To ensure the correct encoding of the associations, participants had to name the correct location and got feedback for each trial if their response was correct or not. After participants had heard all 20 items and named their location, they proceeded to the recognition-test phase.

Recognition-test phase During the recognition test, participants executed one of the movement conditions (blocked design: walking forward, walking backward, standing) meanwhile the items of the encoding phase were again presented auditorily, one at a time (just as in the encoding phase, except that the items were presented without the symbol on the screen that indicated the corresponding temporal location). Participants were asked to indicate vocally whether the food belongs to the space behind ("hinten") or ahead ("vorne").

The same procedure (including the encoding phase and the recognition-test phase) was repeated three times in different movement conditions with new sets of items (see Appendix A, Table 1).

2.1.4 Data Analysis.

Statistical analyses were performed with R (RStudio Team, 2015). Responses given previous to stimulus offset (= 666 after stimulus onset) or exceeding 6000 ms were excluded from all analysis.

To analyze response accuracy (= number of "correct" or "incorrect" items per condition and spatial/temporal association), a generalized linear mixed model with a binomial distribution was conducted (glmer function, RStudio Team, 2015), including Subject as random factor. P-values of the main effects were obtained by likelihood ratio tests of the effect in question (Condition, Response) against a baseline model (containing only the random effect and the fixed intercept). P-values of the interaction effects were obtained by likelihood ratio tests of the effect in question (Condition * Response) against the same model without the interaction term. After fitting the model, the correlation matrix of the fixed effects, and the qqplot of the random effects were examined.

To analyze response times, we first analyzed if response times are correlated with age, "Vividness of mental imagery", trial number, or block number. To examine the hypothesized interaction, a linear mixed model was calculated (lme function, ML estimation, RStudio Team, 2015). To allow for the within-group errors to be correlated, Subject, Condition, and Response were included as random factors. P-values of the main effects were obtained by likelihood ratio tests of the effect in question (Condition, Response) against a baseline model (containing only the random effects and the fixed intercept). P-values of the interaction effects were obtained by likelihood ratio tests of the effect in question (Condition * Response) against the same model without the interaction term. Approximate normal distribution of the residuals was analyzed by plotting fitted values against standardized residuals.

Post hoc tests were conducted by single *t*-tests between the contrasts of interest (ahead vs behind in each condition), and Cohen's d is reported as effect size. The significance criterion for all analyses was alpha = .05.

2.2 Results and Discussion Experiment 1

2.2.1 Answers.

We examined whether whole-body movements influence the number of correct answers for each spatial association. Responses given previous to stimulus offset (= 666 after stimulus onset) or exceeding 6000 ms were excluded from the analysis (= 2 %).

For a summary of the results, see Fig. 1. On a descriptive level, participants correctly recognized the same number of "ahead" and "behind" items during each condition. The statistical analysis confirmed that the frequency of correct and incorrect answers of "ahead" and "behind" items did not differ between conditions. For a detailed description of the model and the model outcome see Appendix B, Table 1.

################################ Figure 1 ####################################

Figure 1. Average number of correct "ahead" and "behind" items plotted for the three different groups (i.e., walking conditions). Error bars represent standard deviations.

2.2.2 Response times.

Response times per answer and condition are plotted in Fig. 2. There was no effect of Condition $\chi^2(1) = .55$, $p = .76$. There was a significant main effect of Response, $\chi^2(1) = 5.35$, $p = .02$. Response times of correct "behind" items (*M* = 1727 ms, *SD* = 589 ms) were faster than the response time of correct "ahead" items (*M* = 1810 ms, *SD* = 543 ms). The Response x Condition interaction was significant $\chi^2(1) = 8.29$, $p = .02$. For a detailed description of the model and the model outcome see Appendix B, Table 2. Visual inspection of residual plots did not reveal any obvious deviations from normality. Post hoc tests revealed that participants answered significantly faster during backward walking to behind-related stimuli (*M* = 1652 ms, *SD* = 565 ms) than to ahead-related stimuli (*M* = 1837 ms, *SD* = 450 ms; $t(28) = 2.65$, $p = .01$, Cohen's d = .49), whereas during forward walking and during standing the response times to behind-related and ahead-related stimuli did not differ.

Neither trial number, block number, VVIQ2-score, nor age correlated with response times. To examine if the order of conditions influenced the interaction, we included order in the full model and compared it against the model without order. Results revealed no significant influence of order.

################################ Figure 2 #####################################

Figure 2. Response times for "behind" and "ahead" items in the three conditions. Error bars represent 95 % within-subjects confidence intervals appropriate for evaluating the effect of movement direction within participants.

In sum, results partly confirmed the hypothesis that whole-body movements influence the processing of space-related stimuli: Although no differences were found for accuracy, the analysis of the response times showed an interaction of movement condition and space-related stimuli. In case of backward walking, the difference was as expected: The responses to ahead-related stimuli during backward walking were slower compared to behind-related stimuli during backward walking. Surprisingly, in case of forward walking, there was no difference between ahead- and behind-related stimuli. During standing, the response times to ahead- and behind-related stimuli did not differ (Fig. 2). These results are critically discussed in the general discussion. In Experiment 2 we predicted similar effects of movement direction on stimuli that are located in time and put this hypothesis to test.

3. Experiment 2

In Experiment 2, we examined the influence of walking on *temporal* concepts. To this end, in an encoding phase, participants learned object-time associations (e.g., apple – past). The instruction was the only difference between Experiment 1 and Experiment 2: In Experiment 1, participants were asked to remember the *spatial* location of the stimuli, whereas in Experiment 2, participants were asked to remember the *temporal* location of the stimuli. In a following recognition-test phase participants vocally assigned objects to the previously learned location in time (past, future) while performing a whole-body movement condition. The procedure of encoding and recognition-test phase was repeated three times, with three different movement conditions (walking forward, walking backward, or standing on a treadmill).

3.1 Method

3.1.1 Participants.

We invited the same number of participants into the lab as in Experiment 1. The total sample was therefore 57 participants (37 female). The mean age of the participants was 23.6 years (*SD* = 4.82). Primary inclusion criteria for the participants were age (between 18 and 65) and no health restrictions with regard to their walking abilities. All participants were included in the analysis of the answers. To ensure data quality, only participants that achieved the required number of at least 50 % correct answers per condition and temporal association were included in the analysis of the response times (*N* = 35). All participants provided informed consent and were free to withdraw from testing at any time. The experiment was approved by the ethical committee of the local institution.

3.1.2 Apparatus and Stimulus.

The apparatus and stimuli were the same as in Experiment 1, with the only difference being that in Experiment 1 participants were asked to associate the objects with a location in space (10 meter in ahead, 10 meter behind), whereas in Experiment 2 participants were asked to associate the objects with a location in time (10 years in the past, 10 years in the future).

3.1.3 Procedure.

The procedure was the same as in Experiment 1. Yet, the instructions in the encoding phase and recognition-test phases were modified as follows:

Encoding phase During the encoding phase participants were instructed as follows (translated from German, and adopted from Saj et al., 2013):

"Imagine you are an actor, learning the characteristics of a fictive personality. 10 years back in the past you liked certain foods. 10 years in the future you will like certain foods. In the following you will learn, which foods you liked in the past and which foods you will like in the future. To which time the food belongs is indicated by the symbols you already learned: Food that you liked in the past is indicated with a (°) and food that you will like in the future is indicated with a (*)."

Recognition-test phase The recognition test was equal to Experiment 1, with the only difference being that in Experiment 1 participants vocally indicated whether an item belongs to the space behind (“hinten”) or the space ahead (“vorne”), whereas in Experiment 2 participants vocally indicated whether an item belonged to the past (“Vergangenheit”) or the future (“Zukunft”).

3.2 Results and Discussion Experiment 2

3.2.1 Answers.

We examined whether whole-body movements influence the number of correct answers for each temporal association. Responses that were given previous to stimulus offset (= 666 ms after stimulus onset) or exceeding 6000 ms were excluded from the analysis (= 1.3 %).

For a summary of the results, see Fig. 3. On a descriptive level, participants correctly recognized the same number of “future” and “past” items during each condition. The statistical analysis confirmed that the frequency of correct and incorrect answers of “future” and “past” items did not differ between conditions. For a detailed description of the model and the model outcome see Appendix B, Table 3.

################################ Figure 3 ######################################

Figure 3. Average number of correct “future” and “past” items plotted for the three different groups (i.e., walking conditions). Error bars represent standard deviations.

3.2.2 Response times.

Response times per answer and condition are plotted in Fig. 4. There was a significant main effect of Condition, $\chi^2(1) = 8.74$, $p = .01$. Post hoc tests revealed that mean response time during walking backward (M = 1748 ms, SD = 493 ms) was slower than the mean response time during standing (*M* = 1630 ms, *SD* = 415 ms). There was also a main effect of Response, $\chi^2(1) = 4.63$, $p = .03$. The mean response time of correct "past" items (*M* = 1660 ms, *SD* = 444 ms) was faster than the mean response time of correct "future" items (*M* = 1716 ms, *SD* = 481 ms). More important, the Response x Condition interaction was significant $\chi^2(1) = 11.98$, $p = .003$. For a detailed description of the model and the model outcome see Appendix B, Table 4. Visual inspection of residual plots did not reveal any obvious deviations from normality. Post hoc tests indicated that participants answered significantly faster during backward walking to past-related stimuli (*M* = 1676 ms, *SD* = 385 ms) than to future-related stimuli (*M* = 1820 ms, *SD* = 453 ms; $t(35) = 3.59$, $p = .001$, Cohen's d = .6), whereas during forward walking the response times to behind-related and ahead-related stimuli did not differ.

Neither trial number, block number, VVIQ2-score, nor age correlated with response times. Furthermore, to check if the order of conditions influenced the interaction, we included order in the full model and compared it against the model without order. Results revealed no significant influence of order.

################################ Figure 4 ####################################

Figure 4. Response times for "past" and "future" items in the three conditions. Error bars represent 95 % within-subjects confidence intervals appropriate for evaluating the effect of movement direction within participants.

In sum, results partly confirmed the hypothesis that whole-body movements influence the processing of time-related stimuli: Although no differences were found in the answer direction of the incorrect answers, the analysis of the response times showed an interaction of movement condition and time-related stimuli. In case of backward walking, the interaction was as expected: The responses to future-related stimuli during backward walking were slower compared to past-related stimuli during backward walking (and also slower compared to all other time-movement combinations). Surprisingly, in case of forward walking, there was no difference between future- and past-related stimuli. During standing, the response times to future- and past-related stimuli did not differ (Fig. 4).

4. General discussion:

This study investigated the potential impact of movements on the activation of spatial and temporal concepts. Based on Lakoff and Johnson's conceptual metaphor theory (1980) and theories of embodied cognition (Shapiro, 2011), we predicted that directional movements should systematically activate specific spatial concepts as well as specific temporal concepts: Forward walking should activate ahead- and future-related concepts, whereas backward walking should activate behind- and past-related concepts. To test this, we invited participants to walk forward, backward, or stand on a treadmill and examined whether walking in either direction changed their processing of previously learned space-related (Experiment 1, "behind" or "ahead") or time-related (Experiment 2, "past" and "future") stimuli.

In Experiment 1, results indicated an incongruence effect of directional movements on space-related stimuli: During backward walking, "behind" stimuli were processed faster than "ahead" stimuli. During forward walking and during standing there were no differences between the processing speed of "behind" and "ahead" stimuli. In Experiment 2, results suggested the same, selective incongruence effect of directional movements on time-related stimuli: during backward walking, "past" stimuli were processed faster than "future" stimuli. During forward walking and during standing there were no differences between the processing speed of "past" and "future" stimuli. The similar incongruence effects of backward walking and processing space- and time-related stimuli provide evidence that directional (backward) movements might activate specific spatial concepts and specific temporal concepts.

The present results are consistent with the general notion that our concepts of space and time are linked (Eikmeier et al., 2013; Lakoff & Johnson, 1980) and that these concepts interact with sensorimotor processes (Shapiro, 2011). The advantage of the present study is that the effect was independent of the stimuli per se, because the spatial (Experiment 1) and temporal (Experiment 2) stimuli were equal and the difference showed only in the association of the respective concepts: participants associated stimuli with either spatial (Experiment 1: behind, ahead) or temporal (Experiment 2: past, future) concepts. In both experiments, the backward movement had an effect on the processed concepts, whereas the forward movement had not. Why did only backward motion affect the processing of space- and time-related concepts?

With respect to results stemming from studies using comparable paradigms to the ones used in the study at hand, our findings are absolutely in line with previous work, indicating either no (Hartmann & Mast, 2012) or smaller effects of forward compared to backward movements with respect to incongruence effects between movement direction and temporal location (Rinaldi, Locati, Parolin, Bernardi, & Girelli, 2016) as well as movement direction and number magnitude (Marghetis & Youngstrom, 2014). A possible explanation for this selective effect might be related to the different levels of familiarity with different walking conditions. We normally walk forward in our daily lives, therefore we are very familiar with walking forward (or being passively moved forward, e.g. in a car) and processing all types of spatial and temporal concepts at the same time. Walking backward is much more unfamiliar, and the activation of a somehow more general concept of space or time located behind or in the past might therefore be larger compared to forward walking. In several experiments and a theoretical discussion about grounded congruency effects, Lebois, Wilson-Mendenhall, and Barsalou (2015) highlight the fact that certain features of concepts become dynamically active only when the context makes them salient. Our results may support this theoretical claim about grounded congruency effects, as less familiarity and therefore less automaticity is one of the factors that are able to make a certain feature of a concept more salient. If movement familiarity is the crucial aspect for the emergence of the selective incongruence effect found in this study, then the effect should decline with increasing experience in backward walking. In future studies, this could systematically be tested by, for example, implementing different numbers of training sessions in backward walking, including a standing or walking forward condition that is less familiar, or testing an expert population that is more familiar with backward walking – e.g. experts, who practice "running backwards" as a competitive sport. Coupled with these manipulations it would be sensible to implement a measure of the cognitive and physical effort that participants expend on the task.

An alternative interpretation of the findings relates to the fact that the task involved two stages of processing: the processing of the stimulus (i.e., deciding whether it was "ahead" or "behind"), and the generation of the response (i.e., calling out "ahead" or "behind"). It is conceivable that the advantage in response times in Experiment 1 occurred at the response selection stage, but not the processing of the stimulus and decision about the spatial category. It could be that people are faster in saying behind during backward walking because the "solution word" describes the walking direction, whereas "ahead" is in contrast to it. If so, the results from Experiment 1 might also be attributed to a congruity effect between response and walking backward/forward[2]. As this issue concerns Experiment 1, but not Experiment 2, where no spatial category existed, the interpretation of movement effecting the processing of the stimulus might be favored. Nevertheless, future studies should address this issue, for example, by selecting responses that do not have a congruity effect with movement direction (e.g., say "Da" for behind and "Do" for ahead).

In addition, some methodological aspects deserve to be discussed in more detail. For the response time data, we decided to maintain a high data quality by setting the inclusion

[2] We thank an anonymous reviewer for suggesting this alternative interpretation.

criteria to at least five correct responses in every condition and spatial/temporal association per participant. This resulted in the desired exclusion of participants that only guessed the correct associations, but also in a high drop-out rate. To avoid a high drop-out rate, in future studies, one could think about implementing a longer encoding phase or taking stimuli that inherently belong to the future or the past (e.g., “childhood”, “Holiday on Mars”). One argument against stimuli that inherently belong to the future or the past is that only very few words exist that inherently belong to a space in ahead or behind (exception: the words “ahead” and “behind” itself, or body-related words as “nose” or “spine”), which would make a direct comparison of spatial and temporal associations difficult. Another argument against this kind of stimuli is that it is almost impossible to keep the words equally long, which complicates the interpretation of response times (Lewis & Frank, 2016). Although, based on the reasons named above we decided against stimuli that inherently belong to the future or past in the study at hand, future studies should investigate the differential influence of directional movements on inherently time-related stimuli.

The implications of the notion that temporal concepts are embodied, which is reflected in the present study by an incongruence effect between real movement direction and abstract temporal representation, require further examination. For example, besides the assumption that abstract concepts are built on concrete sensorimotor experiences, embodied cognition theories (e.g., Shapiro, 2011) assume a bidirectional link between sensorimotor and cognitive processes. To investigate if the assumption of bi-directionality also holds for abstract concepts, a fruitful route for future studies is to test whether the activation of specific spatial and temporal concepts influences movement parameters such as movement time or movement distance.

5. Conclusion

The present results support the general notion that concepts of space and time are linked (Eikmeier et al., 2013; Lakoff & Johnson, 1980) and that these concepts interact with sensorimotor processes (Shapiro, 2011). Although directional movements did not lead to more correct answers of space- or time-related stimuli that were located in the same direction, directional movements led to faster response time with space- or time-related stimuli that were located in the same direction. The activation of a spatial/temporal concept by means of whole-body movements was specific to the movement direction. In two experiments, backward walking affected the processing of spatial/temporal concepts, whereas forward walking did not affect the processing of spatial/temporal concepts. These results add evidence to previous research showing a similar, selective effect of passive backward motion on time-related stimuli (Hartmann & Mast, 2012). Potential moderating factors such as movement familiarity or visual flow need to be further examined in future research.

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Appendix A

Stimulus material

Table A1.

List of objects

Type of object	Object (German)	Object (English)
Food	Ananas	Pineapple
Food	Banane	Banana
Food	Bohnen	Beans
Food	Braten	Roast
Food	Brezel	Pretzel
Food	Butter	Butter
Food	Erbsen	Peas
Food	Kaffee	Coffee
Food	Kaviar	Caviar
Food	Kuchen	Cake
Food	Linsen	Lentils
Food	Mandel	Almond
Food	Melone	Melon
Food	Nudeln	Pasta
Food	Orange	Orange
Food	Pommes	Fries
Food	Rosine	Raisin
Food	Salami	Salami
Food	Spinat	Spinach
Food	Tomate	Tomato
Clothes	Anorak	Anorak
Clothes	Bikini	Bikini
Clothes	Blusen	Blouses
Clothes	Bolero	Bolero
Clothes	Fliege	Bow tie
Clothes	Gewand	Robe
Clothes	Gürtel	Belt
Clothes	Jacken	Jackets
Clothes	Kittel	Gowns
Clothes	Mantel	Coat
Clothes	Pyjama	Pyjamas
Clothes	Schuhe	Shoes
Clothes	Socken	Socks
Clothes	Stulpe	Ankle warmers
Clothes	Tasche	Pocket
Clothes	Tracht	Traditional costumes
Clothes	Trikot	Jersey
Clothes	Tshirt	Shirt
Clothes	Tunika	Tunic
Clothes	Umhang	Cloak
Furniture	Bürste	Brush
Furniture	Dusche	Shower
Furniture	Füller	Pen
Furniture	Hocker	Stool
Furniture	Kissen	Pillow
Furniture	Kleber	Glue
Furniture	Klinke	Handle
Furniture	Komode	Sideboard
Furniture	Lappen	Cloth
Furniture	Laptop	Laptop
Furniture	Löffel	Spoon
Furniture	Messer	Knife
Furniture	Ordner	Folder

Furniture	Pfanne	Pan	662
Furniture	Poster	Poster	
Furniture	Schere	Scissors	
Furniture	Sessel	Armchair	
Furniture	Teller	Plate	
Furniture	Treppe	Stairs	
Furniture	Tresen	Counter	

Appendix B

Detailed model information

Table C1.

*Model outcome for the model: glmer(response_accuracy ~ Response * Condition + (1|participant) + (1+Condition|participant) + (1+Response|participant), data = data_space, family = binomial(link="logit")))*

<table>
<tr><th>Dependent variable</th><th>Response variable</th><th>Estimate</th><th>Standard Error</th><th>Z value</th><th>Pr(>|z|)</th></tr>
<tr><td>Response accuracy</td><td>Intercept</td><td>12.91</td><td>19.24</td><td>.67</td><td>.5</td></tr>
<tr><td></td><td>Response</td><td>-14.26</td><td>19.24</td><td>-.74</td><td>.46</td></tr>
<tr><td></td><td>Condition (backward vs standing)</td><td>-.02</td><td>.19</td><td>-.13</td><td>.89</td></tr>
<tr><td></td><td>Condition (forward vs standing)</td><td>.01</td><td>.18</td><td>.08</td><td>.94</td></tr>
<tr><td></td><td>Response x Condition (backward vs standing)</td><td>-.02</td><td>.22</td><td>-.11</td><td>.92</td></tr>
<tr><td></td><td>Response x Condition (forward vs standing)</td><td>-.22</td><td>.22</td><td>-.81</td><td>.42</td></tr>
</table>

Table C2.

*Model outcome for the model: lme(response_time ~ Condition * Response, random = list(~1|participant, ~1+Condition|participant, ~1+Response|participant), method = "ML", data = data_space)*

Dependent variable	Response variable	Estimate	Standard Error	t-value	p-value
Response accuracy	Intercept	1812.01	49.82	36.38	< .001
	Response	-45.57	48.57	-.94	.35
	Condition (backward vs standing)	31.98	57.91	.55	.58
	Condition (forward vs standing)	-25.83	58	-.45	.66
	Response x Condition (backward vs standing)	-133.05	60.32	-2.21	.03
	Response x Condition (forward vs standing)	29.09	60.42	.48	.63

Table C3.

*Model outcome for the model: glmer(response_accuracy ~ Response * Condition + (1|participant) + (1+Condition|participant) + (1+Response|participant), data = data_time, family = binomial(link="logit")))*

<table>
<tr><th>Dependent variable</th><th>Response variable</th><th>Estimate</th><th>Standard Error</th><th>Z value</th><th>Pr(>|z|)</th></tr>
<tr><td>Response accuracy</td><td>Intercept</td><td>-1.76</td><td>.16</td><td>-10.7</td><td>< .001</td></tr>
<tr><td></td><td>Response</td><td>-.01</td><td>.17</td><td>-.1</td><td>.93</td></tr>
<tr><td></td><td>Condition (backward vs standing)</td><td>.37</td><td>.16</td><td>1.59</td><td>.11</td></tr>
<tr><td></td><td>Condition (forward vs standing)</td><td>.11</td><td>.16</td><td>.35</td><td>.73</td></tr>
<tr><td></td><td>Response x Condition (backward vs standing)</td><td>.02</td><td>.23</td><td>.19</td><td>.85</td></tr>
<tr><td></td><td>Response x Condition (forward vs standing)</td><td>-.1</td><td>.23</td><td>-.3</td><td>.77</td></tr>
</table>

Table C4.

*Model outcome for the model: lme(response_time ~ Condition * Response, random = list(~1|participant, ~1+Condition|participant, ~1+Response|participant), method = "ML", data = data_time)*

Dependent variable	Response variable	Estimate	Standard Error	t-value	p-value
Response accuracy	Intercept	1656.76	43.83	37.80	< .001
	Response	-21.18	35.18	-.6	.55
	Condition (backward vs standing)	175.81	42.50	4.14	< .001
	Condition (forward vs standing)	47.15	37.86	1.25	.21
	Response x Condition (backward vs standing)	-123.86	43.24	-2.86	.004
	Response x Condition (forward vs standing)	11.57	42.36	.27	.78