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It's All in the Past: Deconstructing the Temporal Doppler Effect

Aleksandar Aksentijevic and John Melvin Gudnyson Treider

University of Roehampton, London

Author note:

Aleksandar Aksentijevic, Department of Psychology, University of Roehampton;

John Melvin Gudnyson Treider, Department of Psychology, University of Roehampton.

Correspondence concerning this article should be addressed to Aleksandar

Aksentijevic, Department of Psychology, University of Roehampton, Whitelands College,

Holybourne Avenue, London, SW154JD UK. E-mail: a.aksentijevic@roehampton.ac.uk. Tel:

++44 208 392 5756. Fax: ++44 208 392 3527.

Abstract

A recent study reported an asymmetry between subjective estimates of future and past distances with passive estimation and virtual movement. The temporal Doppler effect refers to the contraction of future distance judgments relative to past ones. We aimed to replicate the effect using real and imagined motion in both directions as well as different temporal perspectives. To avoid the problem of subjective anchoring, we compared real- and imagined-, ego- and time-moving conditions to a control group. Generally, Doppler-like distortion was only observed in conditions in which the distance between the participant and a frontal target increased. No effects of temporal perspective were observed. The "past-directed temporal Doppler effect" presents a challenge for the current theories of temporal cognition by demonstrating absence of psychological movement into the future. The effect could open new avenues in memory research and serve as a starting point in a systematic examination of how the humans construct future.

Keywords: Temporal Doppler effect, temporal perspective, time line, time perception, distance judgment

1.1 Introduction

Understanding the deep connection between space and time remains one of the most exciting and difficult challenges for psychology, with accumulating evidence indicating that temporal cognition relies heavily on spatial concepts (e.g. Casasanto & Boroditsky, 2008). A relationship between space and time is a close one to the extent that one can justifiably describe human experience as being embedded in a space-time continuum. Once we attempt to treat space and time separately, we realize that time is difficult if not impossible to define independently (Boroditsky, 2000) and that describing time generally requires spatial analogies and metaphors (Matlock, Ramscar & Boroditsky, 2005). Time appears to be located on an imaginary line which stretches along the line of sight (e.g. Hartmann & Mast, 2012). In addition, despite the fact that it cannot be experienced directly, time is perceived as a dynamic medium possessing the qualities of movement and flow (Bergson, 1922). From the first-person perspective, future is conceptualized as a region which lies in front of the observer and past as a domain situated caudally, behind their back.

How far can the space/time analogy be taken? A recent study seems to indicate that the spatial metaphor is not just a figure of speech or a mode of thought, but that the subjective metric of temporal "space" is distorted by the mental movement along the imaginary time line. Inspired by a well-documented physical phenomenon, Caruso and colleagues (Caruso, Van Boven, Chin & Ward, 2013) proposed that future- and past-duration judgments exhibit asymmetry analogous to the physical Doppler effect (Doppler, 1842). In three studies, Caruso et al. asked participants to estimate past and future distance of one month (Study 1a), one year (Study 1b) and with reference to a fixed date (Valentine's Day; Study 2). Finally, participants estimated future and past distances while being exposed to virtual motion (vection; Study 3). In all three studies, participants consistently underestimated the former relative to the latter distance. The contraction of future distances suggested a dynamic

interaction between the observer and the medium of time. If the observed effect is indeed Doppler-like, the experienced movement through time should compress the subjective time line in the direction of the future and expand it in the opposite direction. This way, even though equal distances are projected onto it, the compression of future intervals leads to a relative underestimate of future distances.

In addition to the three main studies, Caruso et al. carried out three follow-up studies aimed at examining possible confounds. To test for the common assumption that different cognitive processes operate on two temporal directions (past is remembered and future is imagined), they asked participants to imagine taking part in an experiment one month away either in the past or in the future. To control for the difference in prototypicality of two mental domains, Caruso et al. asked participants to estimate past and future intervals from concrete vs. abstract target points. Finally, to examine whether the content populating the past portion of the time line could have made the past appear more distant, they prompted participants to list tasks they intended to complete within a three-week period. In all three cases, the results supported the temporal Doppler effect (TDE) hypothesis.[1]

Caruso et al.'s findings have potentially important implications for theories of time perception and memory. If subjective experience of time is analogous to spatial movement, other properties of the temporal medium could be investigated and charted systematically using physical analogues. For instance, one could measure the speed of temporal motion and relate it to major individual differences such as age, mood or psychopathological factors. However, before such a bold step could be taken, it is necessary to examine carefully the premises and findings underpinning Caruso et al.s claim.

1.1.1 Psychophysical properties of mental time travel

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[1] All Caruso et al.'s studies were between-subjects so that each participant made only one estimate (either past or future).

If the future is contracted relative to the past, what could be causing the contraction? The model to which the authors allude can be called the TDE model. Here, temporal distance is judged from the present to an imagined or remembered event. Mental time travel distorts the temporal metric in a way that resembles the distortion of the physical medium (Figure 1). The contraction of the frontal portion of the time line (from the observer to some future event) is accompanied by the dilation of the past portion. This causes an equidistant past event to appear further away. Although attractive, this model rests on certain assumptions. First, it requires mental time to behave in a manner similar to a physical medium (e.g. air) which allows consequences of movement to be felt and measured. Second, the TDE model presupposes a subjective time line on which experiences are ordered and which extends freely in both temporal directions. This requirement is crucial. For Caruso et al.'s claim to be true, the future portion of the time line must be real and not a projection or extrapolation of past experience (i.e. a function of "episodic future thinking", Atance & O'Neill, 2001, in which case the effect should be called "prospective memory contraction"
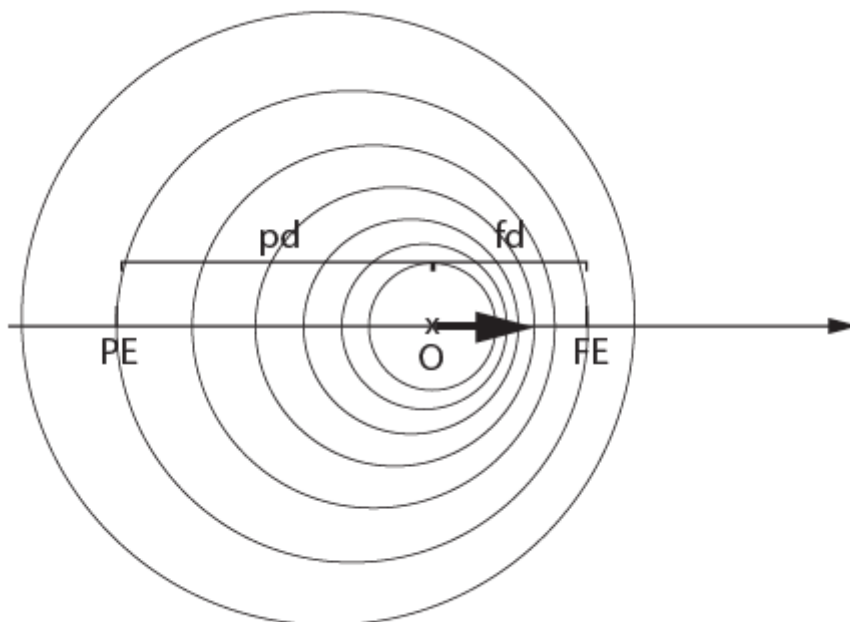
Figure 1. Temporal Doppler effect. The motion of the observer (O) through the medium of time (or movement of time relative to the observer) compresses the frontal portion of the time line and dilates its caudal portion. As a result, the distance (fd) from a future event (FE) appears shorter than the distance (pd) from a past event (PE).[2]

If future distances are contracted relative to past distances they must lie on a single time line. It follows that past and future estimates must be governed by a single metric. What kind of metric could underpin subjective time? Classical psychophysical theories of time estimation (e.g. Eisler, 1976) are not helpful here because they abstract time intervals from their experiential context (e.g. Conway & Pleydell-Pearce, 2000). The only exception could be the consistent finding that short intervals are dilated and long ones compressed relative to the linear metric (see also Ferguson & Martin, 1983). Psychological past is a continuum filled with a sequence of remembered events that fade away losing distinctiveness and relevance

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[2] The model described here assumes, in line with the standard definition of the Doppler effect, that interaction between the observer and a medium distorts the latter. Although Caruso et al. do not explicitly address this point, it logically follows from their (justified) focus on the dynamic relationship between the observer and the observed (see introductory paragraphs on p. 530).

(e.g. Burt & Kemp, 1991). Private memories encoded within the context of public events and knowledge provide markers against which an estimate can be evaluated. In addition, several studies have revealed that temporal distance closely depends on the amount of information one possesses about a particular event. Specifically, people tend to judge as closer the events that are better memorized (Brown, Rips & Shevell, 1985; Hinrichs, 1970). This could imply that more distant events (that are not so well memorized) are judged as being disproportionately more remote. Not surprisingly, people also experience temporally closer events as more emotionally meaningful (Bratfisch, Ekman, Lundberg & Kruger, 1971).

The same authors observed a power law exponent (Stevens, 1975) of .43 for very long temporal intervals which conflicts with Eisler's report of a larger exponent (.9) for somewhat shorter intervals. This could suggest that a different metric is used in estimating very remote past events. Alternatively, a single nonlinear (likely logarithmic) metric is progressively more compressed, with remote dates and events being crammed together and becoming indistinguishable. Overall, the above evidence is commensurate with a nonlinear (exponential or logarithmic) metric with interval size decreasing with distance and with interval contraction becoming more prominent at very long intervals. This metric is significantly modulated by mnemonic and affective factors—emotionally important or otherwise salient events can introduce additional distortion.

In comparison, little is known about the metric properties of the future time line. The importance of future time perspective (FTP) has been highlighted by motivational research (Simons, Vansteenkiste, Lens & Lacante, 2004). FTP is defined as the present anticipation of future goals. Generally, people with a long FTP experience the psychological distance from a given future goal as shorter than people with a short FTP. Although of great importance for education and social psychology, the concept is clearly subject to individual differences (e.g. age; Lang & Carstensen, 2002) to the extent that makes psychophysical measurement

difficult. Furthermore, the extent of FTP must be related to experience and knowledge. The only way to populate the future portion of the psychological time line with content is to extrapolate from past events even when thinking about future ones. It is therefore difficult to see how a future metric could be created independently of experience and memory.

1.1.2   TDE vs. bisection model of temporal asymmetry

A closer inspection of Caruso et al.'s data revealed that their participants scaled temporal distance. In Study 1a, the target interval was one month and in Study 1b, it was one year. Yet, the proportions of the rating scale (1-10) marked off by future and past distances were almost identical (65th and 72nd and 59th and 70th percentile respectively). Study 3, which used a 9-point scale and a shorter interval (3 weeks), revealed a similar picture (64th and 67th percentile). The proportion changed somewhat (47% and 62% respectively) for a very brief interval (1 week; Study 2). The fact that two such different intervals are located at the same points of identical scales means that rather than using a single subjective scale, respondents create different scales to fit different temporal magnitudes. It appears that Caruso et al.'s participants first adjusted the scale range anchoring the future and past time line in some point against which the distance of the target interval was evaluated. Let us assume a Euclidean time line for the sake of simplicity. If one month is perceived as lying 30 days away in the future (65th percentile), the second anchor is located some 46 days away. In the case of one year, the scale is anchored at 20 months away from the present.

Although the above is a simplification, a strategy of this kind must be used if a similar proportion of the scale is occupied by very different intervals. Rather than judging the distance of an event relative to the present as suggested by Caruso et al., participants deployed a bisection strategy in which the time line is anchored by the observer on one side and an abstract future (future anchor; FA) or past point (past anchor; PA) on the other. The event, whose mental distance is fixed (e.g. one month), is then placed on the line and its

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distance from the other anchor is estimated and then compared with the target interval. On

this scenario, the future estimate might not differ from the past one—it is the location of the
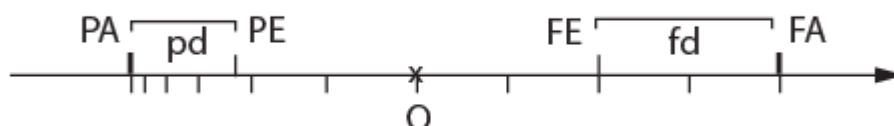
anchor that is causing the asymmetry.

Figure 2.Hypothetical account of the temporal asymmetry causing past overestimates. Due to
compression, PA appears closer to the present than FA. The compression of fd leads to an
overestimate of PE although it is at the same distance from the origin (O) as is FE.

Although Caruso et al. tested their hypothesis against alternative accounts they did not

examine the possibility that future and past scale anchors might be positioned asymmetrically

relative to the observer due to causes unconnected with the flow of time. For instance, given

that the past time line is compressed and the metric of the future line is unknown, PA might

be closer to the present than FA. Comparing the compressed pd segment with the judged

interval could lead to an overestimate of the past interval (see Figure 2). This in turn could

mean that Caruso et al.'s results were not due to a relative contraction of future estimates but

due to overestimates of past distances caused by the compression of the past time line. This

poses the question of how this asymmetry could be investigated if it is implicitly present

before the estimate is made. One way would be to manipulate temporal focus so that, for

instance, future and past estimates in conditions which promote future or past thinking are

evaluated against estimates in a control (no-intervention) condition. Such an approach would

avoid the issue of asymmetrical anchors by causally linking temporal distortion to an explicit experimental intervention.

1.1.3   Future distance and temporal perspective

Although important, metric considerations are not the sole determinant of subjective temporal distance judgments. Most people describe experience of time as dynamic—as conveying a sense of movement or travel. However, these subjective accounts do not specify if this sense of motion is generated by the medium or by the observer. In a series of four studies, Boroditsky and Ramscar (2002) demonstrated that both perspectives co-existed and were interchangeable. The principal findings were that imagined spatial ego movement led to the adoption of the temporal ego-moving perspective in which time is experienced as traveling with (in the direction of) the observer, whereas imagined approach by an object or a person engendered the "time-moving" perspective or the sense that time is traveling towards (in the opposite direction to) the observer (Study 1).[3] Although real movement was associated with the ego-moving perspective, it was not sufficient to sustain it. Ego- and time-moving perspectives were employed interchangeably at different stages of a train journey (Study 4). The authors concluded that thinking about motion rather than actual movement was responsible for the adoption of the ego-moving perspective and that disengagement from spatial thinking made people feel time travelling towards them.[4]

Boroditsky and Ramscar's findings add a layer of complexity to the issue of temporal distance estimation. Although the two studies could not be compared directly, Caruso et al.'s results could be interpreted as reflecting the time-moving perspective. Static subjects exposed to the onrush of time perceive future as closer relative to the receding past. At the same time, if contraction of the future time line is contingent on perspective, we could expect future

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[3] The studies were based around the following ambiguous question: "Next Wednesday's meeting has been moved forward two days. What day is the meeting now that it has been rescheduled?" The interpretation of "moved forward" can vary depending on whether time moves in the same or opposite direction relative to the observer.

[4] An alternative way of describe this phenomenon is to refer to the ego or time as being the locus of motion.

distances to be dilated relative to the past ones once the observer begins moving backwards, especially if they are doing so using their imagination.

1.1.4 The present study

The principal aim of the present study was to replicate the TDE while circumventing the issue of anchoring described above. This was to be accomplished by inducing subjects to shift their temporal focus to the future or to the past and comparing their estimates with those made by a control group which has undergone no intervention. Here, of particular help is the evidence that vection can affect participants' temporal focus (Miles, Karpinska, Lumsden & Macrae, 2010). When presented with illusory forward self-movement, participants tend to focus more on the future whereas with backward vection, their thoughts are directed towards the past (also see Caruso et al., 2013, Study 3). Furthermore, thinking about the future and the past is associated with activation of motor schemas underpinning forward and backward movement (measured as fluctuations in postural sway; Miles, Nind & Mcrae, 2010). This suggested a way of investigating temporal distortion in both directions using movement conditions that could be compared with a no-movement control condition.

Rather than using the future and the past as mutual referents, the present study evaluated the two domains independently with reference to estimates produced by observers who did not take part in the experimental tasks. Another major difference from the original study was that the use of real and imagined motion. Given that the TDE has not been investigated using either form of motion, it was hypothesized that both and especially real movement would amplify the TDE relative to a no-movement condition. Finally, in order to investigate the importance of temporal perspective, both the ego-moving and time-moving conditions (Boroditsky & Ramscar, 2002) were included in the design.

All of the above allowed us to formulate clear hypotheses under the assumption of a single time line. If the TDE model (as posited by Caruso et al.) is correct, we should expect

all conditions in which the distance between the observer and a frontal fixed or moving point decreases, to contract the future portion and dilate the past portion of the mental time line relative to control estimates.[5] The opposite could be expected in conditions in which frontal distance increases. If temporal perspective plays a role, ego-moving and time-moving conditions should produce different outcomes. Specifically, observing (and especially imagining) a person approaching should shorten future estimates. In contrast, moving or imagining ego-movement should prolong future intervals contradicting Caruso et al.'s account (see Table 1 for a full breakdown of conditions and predictions).

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[5] Although increasing frontal distance is assumed to equal decreasing caudal distance, only the former descriptor is used for the sake of parsimony.

Table 1.

Conditions, factors and predictions based on Caruso et al. (2013) and Boroditsky and Ramscar (2002).

Condition	Variable			Caruso et al. (2013)		Boroditsky & Ramscar (2002)	
	Movement[a]	Perspective	Frontal distance	Future	Past	Future	Past
Real forward (RF)	Real	Ego-moving	Decreasing	-	+	+	-
Real backward (RB)	Real	Ego-moving	Increasing	+	-	N/A	N/A
Real towards (RT)	Real	Time-moving	Decreasing	-	+	-	+
Real away (RA)	Real	Time-moving	Increasing	+	-	N/A	N/A
Imagined forward (IF)	Imagined	Ego-moving	Decreasing	-	+	+	-
Imagined backward (IB)	Imagined	Ego-moving	Increasing	+	-	N/A	N/A
Imagined towards (IT)	Imagined	Time-moving	Decreasing	-	+	-	+
Imagined away (IA)	Imagined	Time-moving	Increasing	+	-	N/A	N/A

Note. [a] between subjects; + = dilation, - = contraction

1.2   Method

1.2.1   Participants

The study was approved by the Ethics Committee of the Department of Psychology, University of Roehampton, and was carried out in accordance with the provisions of the World Medical Association Declaration of Helsinki. 60 undergraduate volunteers (49 female) took part in the study ($M = 20.8$ years, $SD = 4.1$ years) after providing informed consent. Two participants were noticeably older than the rest of the sample (38 and 42 years). All participants had normal or corrected-to-normal vision and all provided informed consent and received course credits for taking part in the study.

Although there was a substantial difference in the design of Caruso et al.'s and present study, a general comparison was possible for the purpose of determining adequate sample size. Cohen's d value for Caruso et al.'s Study 1a (one month from now) was 0.52. It was 0.45 for study 1b (one year from now), and 0.51 for study 2 which equals a medium-size effect. The interaction in Study 3 equally produced a medium effect (Cohen's $f = 0.25$). The observed power of studies 1a and 1b was 67 and 68% respectively. The sample size for the present study was determined under the assumption that the experiment should be able to detect a large effect (likely to be produced by real motion, $f = 0.40$; Cohen, 1988). Calculations using G*Power software (Faul, Erdfelder, Lang & Buchner, 2007) showed that a mixed 2 x 2 x 2 design involving a medium correlation between factors (.50) would require 40 participants to detect an effect of that size with the power of 82% at the .001 significance level.

1.2.2   Design

The study employed a mixed design with variables movement (real, imagined), perspective (ego-moving, time-moving) and frontal distance (decreasing, increasing). The

latter two were within-subjects. "Perspective" referred to whether the participant performed or imagined their own movement (ego-moving perspective) or whether they observed or imagined someone else moving (time-moving perspective; Boroditsky & Ramscar, 2002). Finally, "frontal distance" referred to whether the (real or imagined, ego- or time-moving) condition increased or decreased the distance between the participant and a fixed (target) or a moving (experimenter, imagined subject) point located in front of them. To illustrate, both walking forward and observing another person's approach (in reality or imagination) led to a decrease in frontal distance. This produced a set of eight conditions, namely, real forward (RF), real backward (RB), real towards (RT), real away (RA), imagined forward (IF), imagined backward (IB), imagined towards (IT) and imagined away (IA).

1.2.3   Procedure

The experiment was carried out in a corridor located within the psychology department of the University of Roehampton. It required the use of a 9-m section of an 18.5 m long corridor. The width was 1.3 m and the height 2.5 m. Illumination was provided by a combination of natural and artificial light. The end of the corridor faced by the participants was closed off by a door. The starting point was marked by the end line of the carpet. At the other end, 8.18 m away, a cross made out of gaffer tape marked the target location. It also marked the place from or towards which the experimenter (E) walked in the time-moving trials. In ego-moving trials, the target was a black plastic bucket placed on the marked spot. At the start of each session, participants were briefed and asked to sign a consent form and fill out a demographic questionnaire. As all participants had experienced forward motion prior to the experiment (walking towards the experimental room), they were taken to a cubicle and asked to sit still for three minutes.

While in there, they completed a Sudoku task which was supposed to abolish any cognitive or motor effects of preceding movement. Following this, the participants were

shown the metronome and familiarized with the walking tempo. Each participant was assigned either to a real- or imagined-movement group before their demographic information was collected. The former group took part in the following trials: walking forward towards a target (RF), walking backwards away from the target (RB), watching the experimenter walk towards them (RT), and watching the experimenter walk away from them (RA; see Appendix A for instructions). Trial order was counterbalanced across participants using Latin Square design. Immediately after each trial the participants were asked to indicate how long a date three weeks in the future felt on a scale from 1 to 9, with 1 being *not far at all* and 9 being *extremely far*. Then, participants indicated how long one year in the past felt on a scale from 1 to 10 (1 equaling *a really short time from now* and 10 equaling *a really long time from now*). Question order was counterbalanced across participants.

Different timespans and measurement scales were employed in order to ensure a degree of independence between estimates. Giving consecutive estimates of identical intervals on identical scales could have encouraged complacency and a form of acquiescence bias where both distances are automatically judged identical or very similar. More important, using different intervals and scales should preclude influence on one judgment on another. For example if a subject gives a short future estimate, they might feel compelled to compensate by overestimating the past distance (or vice versa). The future interval of three weeks was the same as that used by Caruso et al. in Study 3, and a one-year interval they employed in Study 1b was chosen with regard to the past. As participants in the current study estimated future and past intervals at the same time, future estimates could have affected past ones and vice versa. Further, it was assumed that a large difference in temporal distance would discourage direct comparison of the two time directions, especially since they were assessed on different scales. Like Studies 1a and 1b by Caruso et al., the present study

employed a 9-point scale (1-10) to measure past intervals. An 8-point scale that had been

employed in their Study 3 (1-9) was used in the estimation of the future distance.

Participants in the imagined movement group were required to complete the same

trials, only instead of performing or observing movement, they were asked to stand still at the

starting point, close their eyes and imagine either walking forwards and backwards or a figure

walking towards or away from them (IF, IB, IT and IA, respectively). The experimenter stood

by their side throughout. Prior to the real or imagined forward movement, participants were

asked to judge the distance between the starting point and a target (a black bucket placed on

the floor at the end of the corridor). This was the same distance they were required to traverse

(8.18 meters).

In order to ensure uniform walking speed, at the start of every ego-moving trial, the

experimenter activated a metronome emitting a clearly audible pulse at 60 beats per minute,

with each pulse marking off a step.[6] The metronome was stopped once the participant

reached the target or once the experimenter reached the participant (70 cm face-to-face

distance). In the imagined-movement condition, participants were free to choose when to start

imagining the motion. They instructed the experimenter to stop the metronome once they had

reached the target or once the imaginary subject had stopped walking. An additional 20

participants (control group) provided past and future estimates as in the first two conditions

without performing or imagining movement. Their ratings were used as a baseline against

which the experimental data were evaluated. Participants were instructed not to use their

answers on preceding trials to inform their current judgments. At the end of each session,

they were fully debriefed. An experimental session lasted approximately 35 minutes.

1.3   Results

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[6] The metronome had been used to control walking speed in a study of effects of walking on the dynamics of subjective time estimates (Kiefer et al., 2009; Styns, van Noorden, Moelants & Leman, 2007).

Future and past conditions were analyzed separately. No between-group differences were observed in terms of age or initial distance judgment, as confirmed by one-way between-subjects ANOVAs for all three groups (real, imagined, control). Absence of between-group gender differences was revealed by the same method confirming that experimental manipulation was the salient factor affecting performance. One participant (imagined-movement group) estimated the distance to the target at 40m. Because this was over three times the maximum estimate, their data were removed from further analyses.

Next, mean estimates were computed from the control group to serve as a baseline against which experimental ratings could be evaluated. This group's data were not used in further analyses. The mean future rating was 3.5 on a scale from 1 to 9 ($SD = 1.23$, 44th percentile). This was shorter than the corresponding mean future estimate in Caruso et al.'s Study 3. Averaging their future estimates over forward and backward vection gave a mean of 5.09 ($SD = 1.64$, 63rd percentile). The difference between the two studies was highly significant, $t(98) = 4.05$, $p < .001$.

1.3.1 Relationships between experimental conditions

As a first step, dependencies between experimental conditions were examined using Spearman's rank order correlations. No correlations were found between the initial spatial distance and time estimates (all $p > .20$), bringing into question the assumed direct analogy between spatial and temporal distance judgments. Further, no correlations were found between age and time estimates in any condition or with physical distance estimates. Next, correlations were performed between future and past estimates across all conditions in order to examine if the former were affected by the latter or vice versa. Given that participants estimated temporal distance in both directions, a negative correlation would invalidate our results. Focusing on the control group, no correlation was observed between future and past

estimates ($r_s = .33$, $p = .161$; $N = 20$), suggesting that the ploy of using different intervals and scales was successful. Next, ego- and time-movement conditions were correlated separately for real and imagined movement (see Appendix B, Table 3). In the real-movement group, all conditions were strongly mutually related with regard to future estimates—longer estimates in one condition were associated with longer estimates in all other conditions. The same was observed with respect to past estimates suggesting that a common strategy was used to produce the future and past intervals irrespective of perspective. Participants employed a directional spatial analogy that relied on the change in frontal distance.

A similar relationship was observed with imagined movement, though not as clearly. The relationship between real and imagined movement conditions was illustrated by the significant second-order correlation between real and imagined movement correlations ($r_S = .46$, $p = .013$, $N = 28$). At the same time, real-movement conditions were more strongly intercorrelated than imagined-movement ones, $t(54) = 2.18$, $p = .034$. The IT condition did not correlate with other conditions vis-à-vis future estimates suggesting that it differed substantively from them in terms of estimation strategy. With regard to past estimates, conditions were mutually correlated with the exception of the IT condition which correlated only with the IA condition.

Finally, future estimates were correlated with past ones in order to re-examine the possibility that longer past estimates were associated with shorter future estimates, as predicted by the TDE model. Overall, no negative correlations were observed indicating that the contraction of future intervals did not depend on the dilation of the past ones and vice versa. With real movement, the only condition of interest was RT because it correlated positively with itself (across temporal directions) as well as the other conditions. With imagined movement, IT condition correlated positively with the IF condition. These cross-direction correlations should be contrasted with the absence of future/past correlation in the

control condition. All involved the "towards" condition in which a figure (real or imagined) approached the participant suggesting an ambiguity in assigning a temporal role to the approaching person.

1.3.2 Main analyses

A three-way mixed ANOVA with variables movement, perspective and frontal distance was performed on mean future ratings. The only significant effect was the main effect of frontal distance, $F(1, 37) = 8.64$, $p = .006$, $\eta_p^2 = .19$. The observed power of the effect was 82%—close to the a priori estimate. Increasing frontal distance conditions (RB, RA, IB and IA) produced longer future estimates ($M = 4.33$; $SD = 1.43$; 54th percentile) relative to the decreasing frontal distance conditions (RF, RT, IF and IT; $M = 3.92$, $SD = 1.39$). In order to interpret these results with regard to the control condition, four independent-samples t tests were carried out between control estimates and four decreasing frontal distance conditions. All were nonsignificant (see Appendix C, Tables 4 and 5) indicating that in these conditions participants' estimates were statistically indistinguishable from those produced by the control group. Interestingly, in three conditions (RF, RT and IF), future estimates were *longer* relative to the control condition, that is, in the opposite direction from that predicted by the TDE hypothesis.

Taken together, these results demonstrated that a decrease in frontal distance failed to cause contraction of the future time line as predicted by Caruso et al., and that increase in frontal distance caused its dilation.
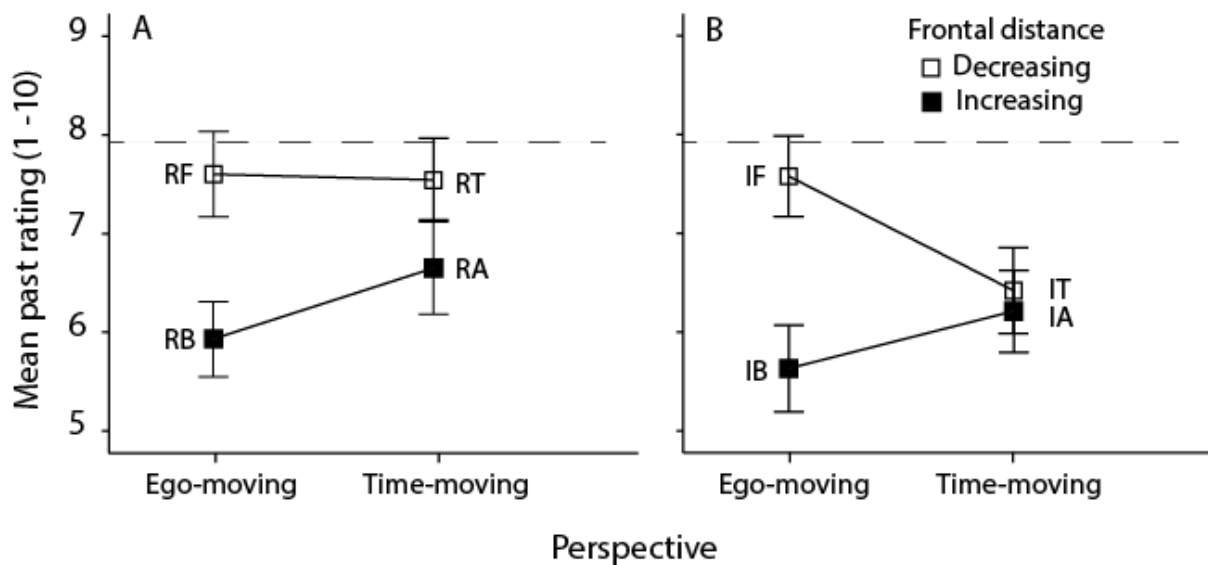
Figure 3. Effects of perspective and frontal distance on past judgments. A: Real movement; B: Imagined movement. Bars denote +- 1 *SEM*. Dashed line marks the mean control past estimate. For the meaning of condition legends, see Table 1.

The mean past rating for the control group was 7.9 (*SD* = 1.16) lying on the 87th percentile.

The mean rating obtained in the related condition by Caruso et al. (2013; Study 1b) was 6.34

(*SD* = 2.13; 70th percentile). An independent-samples t test confirmed that control past

estimates in the current study were significantly longer than those in Caruso et al.'s Study 1b,

$t(116) = 4.65$, $p < .001$. One possible cause of the lower estimate variance in the present study

could have been the fact that our experiment was carried out in restricted space. This should

be contrasted with Caruso et al. who collected their data outdoors. The difference between the

means is addressed in the discussion.

A three-way mixed ANOVA (movement, perspective, frontal distance) was then

performed on mean past ratings. Here, as in the previous analysis, there was a highly

significant main effect of frontal distance, $F(1, 37) = 23.95$, $p < .001$, $\eta_p^2 = .39$. The observed

power was greater than .99. Overall, when frontal distance decreased (when the participant

walked forward or when a person walked towards the participant in both real and imagined

conditions), estimates were close to the control ratings (Figure 3). However, increasing frontal distance conditions were associated with a significant contraction of past estimates. The effect of frontal distance was moderated by perspective, as confirmed by a highly significant two-way interaction, $F(1, 37) = 24.53$, $p < .001$, $\eta_p^2 = .40$. Specifically, the contraction of past distance was more pronounced in ego-moving conditions.

On closer inspection, real and imagined movement produced somewhat different effects, as supported by the significant Group x Frontal Distance interaction, $F(1, 37) = 5.75$, $p = .022$, $\eta_p^2 = .14$. Increasing frontal distance conditions elicited a significant reduction in past ratings. Walking backwards produced shorter estimates relative to observing the experimenter walk away (RB − RA), $t(19) = 2.26$, $p = .035$. This was also the case in the imagined movement condition—imagining walking backwards resulted in larger past contraction compared with imagining a person walking away (IB − IA), $t(18) = 2.91$, $p = .009$. At the same time, with real movement, no effect was found for the decreasing frontal distance conditions (RF, RT; Figure 3A). The source of interaction was the difference between real and imagined movement with regard to decreasing frontal distance conditions. When the participant imagined walking forward (away from the past), their estimates mirrored those in the real movement condition. By contrast, when they imagined a person moving towards them, the perceived distance from the past was reduced significantly relative to the analogous real movement condition (RT), as well as the control condition (IT; Figure 3B).

The above analysis confirmed that the selected sample size provided sufficient power to detect large effects (Appendix D, Tables 6 and 7) especially given that the overall between-condition correlation was somewhat lower than predicted ($M = .42$, $SD = .23$). To examine the relationship between the experimental estimates and those produced by the control group, four independent-samples t tests were carried out between the control scores

and the decreasing frontal distance conditions (RF, RT, IF and IT). In confirmation of the ANOVA results, only the last test produced a highly significant difference, $t(37) = 3.48$, $p < .001$, demonstrating, somewhat unexpectedly, that an image of a person approaching from the front brought participants closer to the past.

1.4   Discussion

The current study sought to replicate the temporal Doppler effect (Caruso et al., 2013) with real and imagined motion by assessing temporal asymmetries against an independent control condition. It also examined the role of temporal perspective (Boroditsky & Ramscar, 2002) in distorting the subjective time line. With respect to the future, our results were clear. Reducing frontal distance produced no effects and increasing it led to future overestimates. The future was judged as being further away irrespective of whether this increase was caused by (real or imagined) backward movement (ego-moving perspective) or passive observation of a receding subject (time-moving perspective) . The absence of future contraction could not be explained in terms of a floor effect—the mean control estimate was at the 44th percentile which should have left sufficient room for the effect to manifest itself. The observed similarity in the effectiveness of real and imagined motion could be predicted from previous research that has demonstrated that similar cognitive processes underpin both forms of movement (Papaxantis, Pozzo, Skoura & Schiepatti, 2002).

The observed dilation of the future estimates in increasing frontal distance conditions can be explained in terms of spatial anchoring. Possessing a solid anchor (starting point or a departing figure) allowed the time to be related to spatial distance with some precision. Moving figuratively towards the past led to an increase in the mental distance from a frontal target. Backward movement (either real or imagined) allowed one anchor to be located at the

initial spatial location. In "away" conditions, this role was delegated to a person. The increasing distance from this anchor led to the stretching of the frontal time line. "Frontal" should not be confused with "future" here. With backward motion, the frontal portion of the time line belongs to the past.

Experimental manipulation affected past estimates in a way that was broadly complementary to its effect on future judgments. Increasing frontal distance conditions led to a significant contraction of past space both relative to control estimates and those produced in decreasing frontal-distance conditions. Thus, increase in frontal distance led to a dilation of the frontal time line *and* a contraction of the caudal time line. In contrast, decreasing frontal distance produced no temporal distortions (with the exception of one condition which behaved contrary to predictions of both TDE and temporal-perspective models). Furthermore, no effects of temporal perspective (Boroditsky & Ramscar, 2002) were observed with regard to time line distortion. Specifically, increasing frontal-distance conditions were effective in dilating the frontal- and contracting the caudal time line irrespective of whether the movement was performed by a participant or another person. At the same time, the former was more effective confirming the importance of motor factors in relating time to space.

The exception was imagined movement where both time-moving conditions (IT, IA) produced past estimates that were significantly shorter than control ones. Both conditions were also less effective than imagined backward movement. This creates an apparent contradiction, namely, that imagining a person moving away or approaching both bring the observer closer to the past. The former complies with the observed general effect of increasing frontal distance. However, the latter is difficult to explain within the current framework. The effect cannot be caused by the impulse to maintain one's personal space (e.g. Lourenco & Longo, 2009), which would compel the participant to mentally retreat towards the past. This is clear from the absence of the effect in the RT condition. A possible

explanation could involve a special status of the human figure/person with regard to temporal

cognition as supported by the atypical pattern of correlations between "towards" conditions

and other conditions (e.g. the fact that IT condition was only correlated with IA condition

with respect to past estimates). A person approaching might bring us closer to the past by

activating memory schemas and associations, especially if that person is known to us (in

contrast with the experimenter who was generally unknown to the participants). On the other

hand, a person walking away leaves us temporally "behind" irrespective of their identity.

Also worth examining is the finding that control past estimates were close to the high

end of the rating scale. The participants saw one year in the past as remote, more so than

Caruso et al.'s participants (87th percentile vs. Caruso et al.'s 70th). Because the control

estimates were so large, estimates produced in the experimental conditions had little room to

move beyond the mean. One year could be too large a distance to allow for past dilation to be

detected, or alternatively, the scale required a larger range. Although this appears

superficially plausible, it is worth remembering that Caruso et al. observed significant

asymmetries using the same interval and scale for the future and the past. In the present

study, a short future interval was estimated against a long past interval. Despite the fact that

temporal asymmetries were evaluated with reference to a control group, each participant

could have mentally compared the two intervals causing the past distance to appear

inordinately long and vice versa.

However, this explanation is invalidated by the absence of correlation between future

and past control estimates. Rather, the inflated past estimates could have been caused by the

restricted experimental space. Two ends of the corridor could have acted as proxy anchors

disproportionately restricting the range of past estimates. This is supported by the fact that the

standard deviation of present estimates was 50% lower relative to the original study. At the

same time, the absence of future distance contraction suggests that there might be no past

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dilation to observe, especially if the recent past is already "stretched" by virtue of greater

discriminability and elaboration in memory. In any case, this issue would be worth

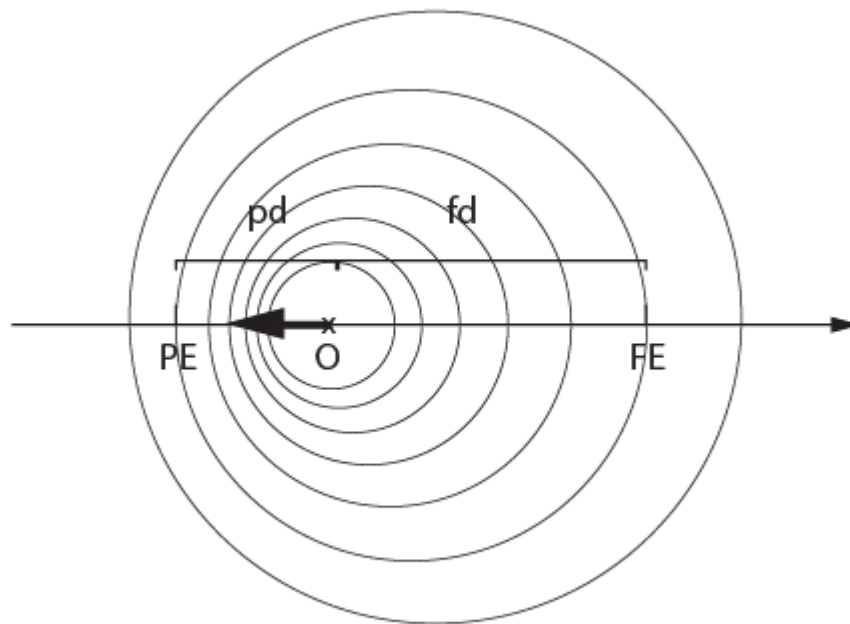investigating further in open-space conditions.

Figure 4. Past-directed TDE. Moving backwards or watching (or imagining) a person moving away dilates future estimates and compresses past ones. This resembles the physical Doppler effect but is observable only with respect to the past.

These points should not detract from the main finding, namely, that forward motion

(real or imagined, active or passive) did not result in a contraction of the future portion of the

time line. Rather, backward movement (active or passive, real or imagined) led to a dilation

of the future interval and a contraction of the past one (Figure 4). Taken either separately or

together, these findings provide evidence for a Doppler-like effect that manifests itself only

with respect to the past portion of the mental time line. This past-directed TDE runs counter

to common intuitive experience of time. Feeling the flow of time we are apt to compare the

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sensation to physical movement. Yet, time can only be thought of if it is experienced—if it is already in the past. Whatever cognitive schema is used to estimate future distances, it must be based on experience and memory. It is here that the spatial analogy breaks down.

With respect to the observation by Boroditsky and Ramscar (2002) that people assume different temporal perspectives depending on whether they are moving forward or being approached (ego-moving and time moving perspective, respectively), our results demonstrate that the metric relationship with the future and the past depends primarily on the perceived or imagined frontal spatial distance, irrespective of whether the motion is executed or observed. With the exception of the atypical IT condition, increase in frontal distance overrode perspective: Past distance contraction (and future distance dilation) was produced by both ego-moving (IB) and time-moving (IA) conditions. At the same time, complementary ego-moving (IF) and time-moving conditions produced no estimate distortions (with the partial exception of IT condition; see Table 2).

Table 2.
Predicted and observed effects

Condition	Caruso et al. (2013)		Boroditsky & Ramscar (2002)		Present study	
	Future	Past	Future	Past	Future	Past
RF	-	+	+	-	0	0
RB	+	-	N/A	N/A	+	-
RT	-	+	-	+	0	0
RA	+	-	N/A	N/A	+	-
IF	-	+	+	-	0	0
IB	+	-	N/A	N/A	+	-
IT	-	+	-	+	0	-
IA	+	-	N/A	N/A	+	-

Note. + = overestimate, - = underestimate

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In the light of recent findings that the change in temporal perspective is strongly affected by emotional valence of imagined (future or past) events (Lee & Ji, 2014), future research could employ emotionally charged references in order to elicit effects of perspective change.

The current results bring into question the notion that the future exists as a mental construct that is independent of the past. A past interval can be anchored in a significant remembered event at one end and the present at the other. Past intervals can be estimated by using distance and/or location information (Janssen, Chessa & Murre, 2006). The presence of two anchors allows construction of a mental scale which possesses a beginning and an end even if lacking equal intervals. This is not the case with the future, which is anchored in the present on one side, but has no absolute (i.e. confirmed by experience) markers on the other. Although one can imagine future goals and events, there is no reason to believe that imagined future distance is anything but an extrapolation of experienced past intervals. At the same time it should be noted that although fairly comprehensive, the present study employed only two time intervals. Further research is needed to establish whether the observed effect hold over a broad range of temporal distances.

However, this does not fully explain the findings by Caruso et al., namely, the consistent compression of future estimates relative to the past ones. What can be causing future anchors to appear closer? Any of the reasons suggested by the authors could be responsible, including different cognitive mechanisms, prototypicality or event density. Perhaps, the asymmetry is associated with the well-documented "planning fallacy" (Kahneman & Tversky, 1979) which reflects the failure to realistically assess future prospects. The contraction of future intervals happens not because of the dynamic effects of mental motion through the medium of time, but because the future is compared with a past which is phenomenally and existentially richer and more elaborated. The movement along the caudal portion of the time line produces Doppler-like effects suggesting that the temporal

medium can exhibit quasi-physical properties. These however are restricted to the time which has been lived and experienced. Furthermore, a recent finding by Maglio and Polman (2014) that people feel psychologically closer to an object when moving towards it (irrespective or real distance) suggests that Caruso et al.'s results could have been due to the inherent location of the future time line (in front of the body) rather than a consequence of temporal flow (but see Footnote 8). [7]

What are the implications of present findings for time estimation and memory research? First, in increasing frontal distance conditions, future estimates were dilated by 10% and past estimates were contracted by about 20%. The difference can be explained by considering the dynamics of mental time travel. The observer is moving away from the second anchor which is located at the initial position along the past portion of the time line. What is in front of them now is the frontal portion of the past time line. Its dilation is caused by movement but the line itself is not pre-stretched, unlike the caudal portion of the past time line. Moving towards the past "slackens" the tension created by the inherent nonlinearity of the past time line, allowing more scope for underestimating past intervals. However, the proximity of the past interval to the anchor could mean that the real degree of contraction of the past time line is lower. If we assume that a change in frontal distance of 8 meters compresses or dilates the past time line by 10%, it would be worth investigating whether this relationship is maintained over larger distances and different intervals. Even more interesting is the possibility that backward movement (real, imagined or virtual) could improve recall of recently acquired information. The quality of recall could be affected by the speed and duration of backward movement as well as its source.

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[7] All of this however does not diminish the importance of Caruso et al.'s contribution which consists in documenting and reliably demonstrating a temporal asymmetry in psychological distance estimation. Further research is needed in order to elucidate its sources.
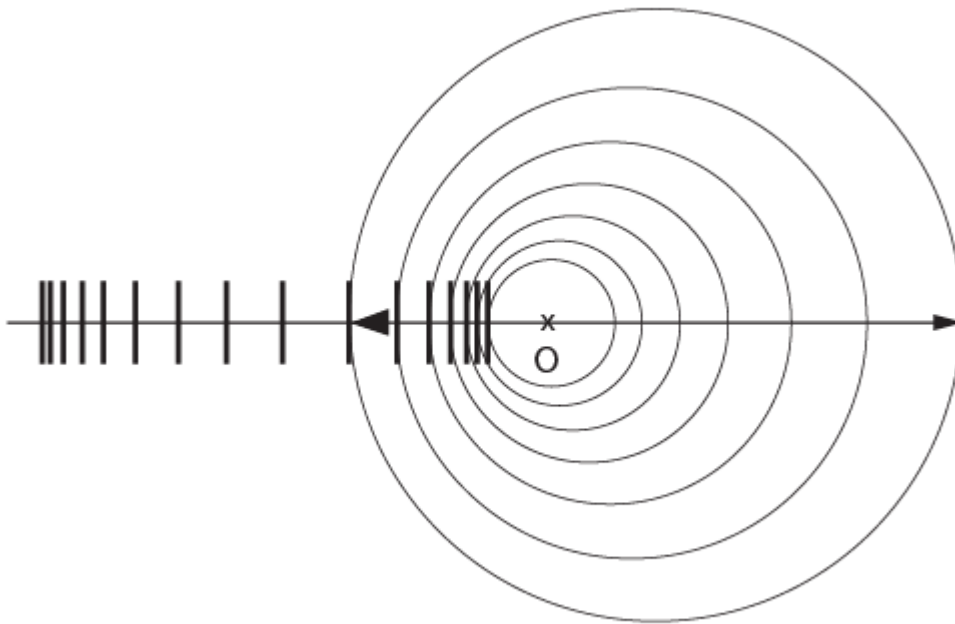
Figure 5. Hypothesised interaction between movement-induced past contraction and the general nonlinear metric of the past time line.

A question arises here about the general shape of the past time line and the interaction with it caused by our manipulation. As stated in the introduction, psychophysical data (Eisler, 1976) suggest that the past time line is nonlinearly distorted with remote past events being compressed and mutually indistinguishable. Figure 5 illustrates one possible way in which the increase in frontal distance affects the past time line. Briefly, mental backward movement compresses the nearest segments of the line reducing the distance from a specific time point. The remainder of the timeline (i.e. that lying beyond the designated point) remains unaffected.
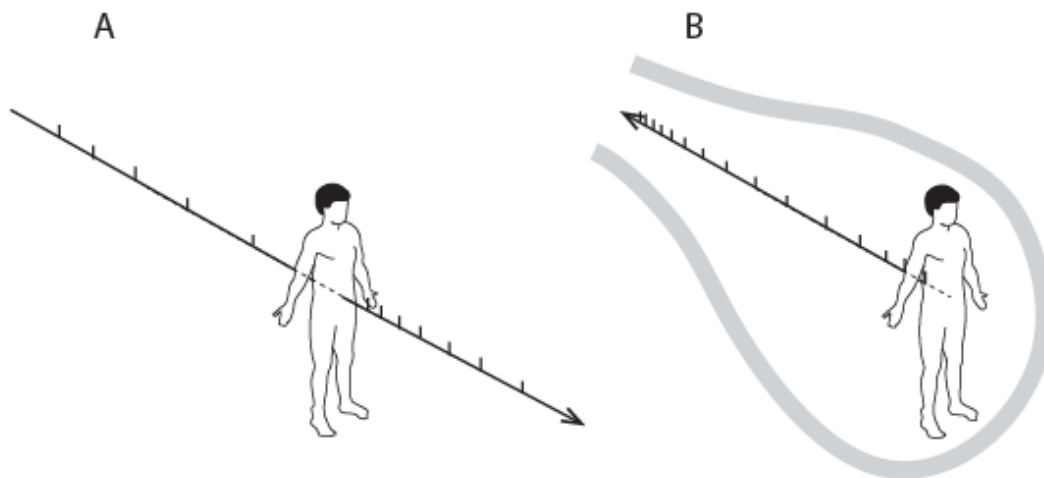
Figure 6. Two models of subjective temporal space. A: A single time line extends from the past into the future (Caruso et al., 2013). Contraction of the frontal part is accompanied by the dilation of the caudal part. B: The "leading edge" model. The time line extends only in the caudal/past direction. The contraction of the line in the vicinity of the body illustrates the findings of the present study.

When drawing analogies between time and space, one must not ignore obvious fundamental differences. Spatial analogies of time (Casasanto & Boroditsky, 2008) can be maintained only up to a point. Physical space is perspective independent and three-dimensional. Its temporal analogue is unidimensional and perspective dependent. It is anchored in the present and the construct we label "future" rests entirely on the cognitive frame built up of memories and knowledge. Although it is possible to imagine the future as being located in front of us (e.g. as a "horizon"), this schema is not based on a psychological time line shown in Figure 6A.[8] The distance from the future can only be measured with

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[8] It should be noted that the frontal projection of the future timeline is not a cognitive universal. For some cultures such as Aymara, the space in front of the body is associated with the past whereas the space behind the body signifies the future (e.g. Núñez & Sweetser, 2006). Further evidence of the dependence of future/past locus on culture comes from a recent study by de la Fuente et al. (2014).

reference to the past, which is not surprising given that the past provides us with multiple anchors in the form of memorized events whose mutual distance we can gauge based on both subjective information and general knowledge (Burt & Kemp, 1991). Future contains no such anchors so that thinking about it must rely on imagination and extrapolation of past experience modulated by hopes and fears. There is a great deal of evidence all the way back to Tulving (1972) and before that future thinking is based on episodic memory. The idea of "episodic future thinking" (Atance & O'Neill, 2001) is clearly based on Tulving's idea of episodic memory and is conceptualised as a future-directed modality of episodic memory. Furthermore, brain research reveals that prospective memory activates the same brain regions (primarily the hippocampus) that are associated with episodic memory and imagery (e.g. Burgess et al., 2001; Martin et al. 2007). A model that fits the observed effects could be described as the "leading edge of reality" model according to which the boundary of the subjective time-space is located in the present and just in front of the body (Figure 7B). Time equals space only if it has been experienced. Subjective temporal space is behind us, in the form of a line marked off by a sequence of ever-receding impressions and memories. When it comes to contemplating the future, this line represents the only stable referent we can use to relate to the Terra Incognita lying before us.

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Appendix A: Instructions

For the RF condition the instructions were: "You are now going to walk towards that black bucket. How long do you believe the distance to be between yourself and the bucket?" After the participant had answered, the experimenter said that he would start the metronome

and they could decide when they wanted to start walking. Once the participant reached the target, the experimenter stopped the metronome and asked them to estimate the distance from the future and the past. In the RB condition, the experimenter said: "You are now going to walk backwards towards the bucket at the pace of the metronome. The experimenter said "stop" once the participant reached the target. Although participants were offered assistance, they all completed the task on their own. In the RT condition, the experimenter stood at one end of the corridor facing the participant and said: "I am now going to walk towards you." He then started the metronome and walked in rhythm with the beat until he reached them (about 70 cm face-to-face). In the real away condition, the experimenter said "I am now going to walk away from you". He stopped walking (and the metronome) once he reached the other end of the corridor.

For the IF movement condition, the instructions were: "You are now going to imagine walking towards that black bucket. How long do you believe the distance to be between yourself and the bucket?" After they had answered, participants were instructed to close their eyes. The experimenter said that he would start the metronome and the participant was free to decide when they wished to start their imaginary walk. When a participant felt that they had reached the end they said "stop". The experimenter stopped the metronome and asked them to provide future and past estimates. Finally, they were told to open their eyes. On IB trials, participants were instructed that they were to imagine walking backwards towards the bucket to the pace of the metronome. They were asked to close their eyes at which point the metronome was started. As in the previous condition, they could decide when they wanted to start the exercise. They said "stop" once they felt that they had reached the end of the corridor. They then gave their estimates and finally opened their eyes.

In the IT condition, participants were instructed as follows: "You are now going to imagine someone walking towards you". Participants were then instructed to close their eyes,

and the metronome was started. They were free to choose the point at which the imaginary

figure started walking. Participants said "stop" when they felt that the imaginary figure had

reached them. Following this, they gave their estimates and then opened their eyes. Finally,

in the IA condition, the instructions were: "You are now going to imagine a person standing

in front of you with their back facing you and you are going to imagine this figure walking

away from you to the end of the corridor." Again, participants closed their eyes and the

experimenter started the metronome. Participants could decide when the imaginary figure

started walking. The rest of the trial was identical to the previous condition.

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Appendix B: Correlations between experimental conditions

Table 3.

Correlations between real movement conditions (Spearman's ρ)

	RB(f)	RT(f)	RA(f)	RF(p)	RB(p)	RT(p)	RA(p)
RF(f)	.57**	.65**	.59**	.25	-.17	.40	.26
RB(f)		.75***	.71***	.42	.17	.53*	.39
RT(f)			.86***	.49*	.25	.65*	.35
RA(f)				.48*	.14	.64**	.42
RF(p)					.66**	.80***	.56**
RB(p)						.57**	.63**
RT(p)							.72***

Note. (f) = future estimate, (p) = past estimate

*$p < .05$ ** $p < .01$ ***$p < .001$

Table 4.

Correlations between imagined movement conditions (Spearman's ρ)

	IB(f)	IT(f)	IA(f)	IF(p)	IB(p)	IT(p)	IA(p)
IF(f)	.72**	.44	.58**	.19	.20	.38	.19
IB(f)		.45	.51*	.23	.20	.44	.26
IT(f)			.30	.76**	.35	.21	.31
IA(f)				-.01	-.07	.34	.05
IF(p)					.66**	.13	.58**
IB(p)						.29	.78**
IT(p)							.55*

Note. (f) = future estimate, (p) = past estimate

*$p < .05$ ** $p < .01$ ***$p < .001$

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Appendix C: t test results for the difference between the control and the decreasing frontal-distance conditions

Table 5.
t tests between control and decreasing frontal-distance conditions (mean control estimate = 3.5)

Comparison	Mean difference	*t*	*df*	*p*	Cohen's *d*	Effect size
C - RF	-0.75	-1.72	38	.095	-0.54	-0.26
C - RT	-0.60	-1.37	38	.178	-0.43	-0.21
C - IF	-0.34	-0.82	37	.413	-0.26	-0.13
C - IT	0.03	0.69	37	.945	0.02	0.01

Note. C = control group; RF = real forward; RT = real toward; IF = imagined forward; IT = imagined toward

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Appendix D: ANOVA output and effect-size estimates

Table 6.
ANOVA output for future estimates

Source	SS	df	MS	F	p	η_p^2	Cohen's f
P	.01	1	.01	.01	.925	.000	.000
P x G	.16	1	.16	.18	.677	.005	.070
Error (P)	34.08	37	.92				
FD	6.24	1		8.64	.006	.189	.482
FD x G	.39	1	6.24	.54	.467	.014	.119
Error (FD)	26.70	37	.39				
P x FD	2.33	1	.72	2.71	.108	.068	.270
P x FD x G	.08	1	.08	.09	.765	.002	.045
Error (P x F x G)	31.86	37	.86				
G	6.78	1	6.78	1.22	.277	.032	.181
Error (G)	206.15	37	5.57				

Note. P = perspective; FD = frontal distance; G = group (between subjects)
Cohen's *f*: .10 - 25 = small, .25 - .40 = medium, .40 + = large. It was computed using the formula $f = \sqrt{\eta_p^2 / (1 - \eta_p^2)}$.

Table 7.
ANOVA output for past estimates

Source	SS	df	MS	F	p	η_p^2	Cohen's f
P	.01	1	.01	.01	.935	.000	.000
P x G	3.68	1	3.68	1.99	.166	.051	.231
Error (P)	68.29	37	1.85				
FD	20.60	1	20.60	24.53	.000	.399	.815
FD x G	4.83	1	4.83	5.75	.022	.135	.395
Error (FD)	31.07	37	.84				
P x FD	44.77	1	44.76	23.95	.000	.393	.805
P x FD x G	1.61	1	1.61	.86	.359	.023	.153
Error (P x F x G)	69.16	37	1.87				
G	8.87	1	8.87	.93	.340	.025	.160
Error (G)	351.57	37	9.50				

Note. P = perspective; FD = frontal distance; G = group (between subjects)
Cohen's *f*: .10 - 25 = small, .25 - .40 = medium, .40 + = large. It was computed using the formula $f = \sqrt{\eta_p^2 / (1 - \eta_p^2)}$.