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Being (un)moved by mental time travel

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ABSTRACT

Mental imagery of events in the past or future, and of unpleasant or pleasant events, has been found to lead to spontaneous backward/forward bodily motions. Both time and emotion are represented along a spatial continuum, and activation of these representations seems to be simulated in spontaneous changes in body posture. We performed a conceptual replication and extension of an earlier study by Miles, Nind, and Macrae (2010) who reported clear postural effects when thinking of the past and the future. We additionally tested whether changes in posture appear when thinking of an emotional event. Volunteers engaged in mental imagery, involving combinations of time intervals and emotions. We simultaneously recorded center-of-pressure (COP) changes. Results revealed neither an effect of imagery of time nor of emotion on body posture. We conclude that embodied effects of imagery of abstract items on body posture may be less robust than suggested by previous literature.

1. Introduction

Humans have the capacity to imagine the subjective experience of objects, events or scenes, in the absence of an immediate physical referent. This is referred to as mental imagery. In mental imagery, various sensory and affective impressions can be generated (intentionally or unintentionally) that resemble the experience when confronted with the real physical counterpart. There is growing recognition that mental imagery is accompanied by changes in bodily states, such as heart rate and respiration (e.g., Decety, Jeannerod, Durozard, & Baverel, 1993; Oishi & Maeshima, 2004), the direction of eye movements (Hartmann, Martarelli, Mast, & Stocker, 2014), subliminal muscle activity (e.g., Guillot et al., 2007) and postural sway (e.g., Boulton & Mitra, 2013). According to some (e.g., Grangeon, Guillot, & Collet, 2011), such bodily manifestations of cognitive activity may be indicative of 'embodiment' effects, meaning that the mental (imagined) content automatically triggers associated bodily responses. In keeping with this view, thought and action are tightly coupled, so that cognitive activity may lead the body to 'resonate' in like fashion (cf. Barsalou, 2008).

Various studies (outlines below) have found evidence for effects of mental imagery on the control of upright standing. An obvious starting point to investigate such effects is by asking subjects to mentally simulate one of several motor activities (e.g., running, grasping), and to record accompanying changes in postural dynamics. More precisely, changes in the center-of-pressure (COP) displacements may reveal whether, and to what extent, postural behavior is affected by mental states. Several studies reported evidence of postural changes that were specific to the imagined motor acts (Boulton & Mitra, 2013;

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Grangeon et al., 2011; Rodrigues et al., 2010; Stins, Schneider, Koole, & Beek, 2015). For example, Grangeon et al. (2011) found that kinesthetic motor imagery of jumping led to greater postural variability than imagery of finger movements. A likely explanation for these effects is that the to-be-imagined motor activity was not completely blocked from the motor periphery, so that participants made unintentional and subliminal postural adjustments that reflected the imagined motor patterns.

Even though such findings are consistent with an embodiment account, they merely indicate an aspecific increase in postural variability as a function of imagery of various motor acts. However, the embodiment account would gain stronger support if body posture were to shift in a specific direction as a function of thought. As a case in point, two intriguing studies found that generating abstract thoughts indeed led to shifts in body posture along the anterior-posterior axis or —more informally—, forward or backward 'leaning'. Miles, Nind, and Macrae (2010) found that thinking about the past vs. thinking about the future (dubbed 'mental time travel', or '*chronesthesia*') had discernible effects on body position during upright standing. More specifically, thinking about the past led subjects to adopt a slightly backward (posterior) body posture, whereas thinking about the future led subjects to adopt a slightly forward (anterior) body posture. These findings suggest that abstract representations, such as the direction of time, are in fact represented along a spatial dimension, and that the activation of such representations leads to directional changes in body posture. This, in turn, is consistent with the notion that symbolic concepts, such as metaphors (e.g., the 'arrow of time'; Miles et al., 2010, p. 222), are embodied in the sensory-motor system (Gallese & Lakoff, 2005). There is evidence from other paradigms for the notion that time is mentally represented along a spatial continuum. Ulrich et al. (2012) examined the differential ease with which forward/backward arm movements could be executed, when participants were presented with sentences describing events that took place in the past or in the future. It was found that forward movements in response to sentences describing future events and backward movements in response to past events led to faster reaction times compared to the alternate (incongruent) mapping. In another intriguing experiment by Hartmann and Mast (2012), seated participants were passively moved either in a forward or backward direction. It was found that categorization of verbal material related to the future was faster when being moved forward compared to being moved backward. However, the expected converse effect with stimuli involving the past was not significant. In sum, there is evidence from reaction time studies that the representation of time is anchored in space. In that regard, innovative behavioral measures such as changes in body posture, may lead to new insights as to how cognition is grounded in sensory-motor modalities, and to what extent the upright body posture provides a physical substrate for cognitive activity (Frazier & Mitra, 2008).

Miles, Christian, Masilamani, Volpi, and Macrae (2014) performed a follow-up study involving mental imagery of social encounters, and they again tested the emergence of differential postural effects. Similar to the representation of time, the representation of social encounters could also prime (whole body) forward/backward responses. Miles et al. (2014), using the same setup as in their 2010 study, indeed found that imagined positive social encounters (imagining meeting a friend) resulted in forward motion of body posture, whereas imagined negative social encounters (seeing a stranger) resulted in backward bodily motion. Interestingly, the effect only showed up from a first-person (egocentric) perspective, and not from a third-person (allocentric) perspective. The authors argued that mental simulation of the social encounters led to sensorimotor reenactments of the events (i.e., approach and avoidance tendencies), which in turn resulted in anterior and posterior displacements of the body, respectively. This latter effect is consistent with posturographic studies that showed that valence of visual stimuli can lead to whole-body approach-avoidance effects, as regards the control of quiet standing (e.g., Hillman, Rosengren, & Smith, 2004) and the control of forward step initiation (e.g., Bouman, Stins, & Beek, 2015; Stins & Beek, 2011). The latter three studies found evidence for the notion that postural changes in the anterior direction couple to positively valenced visual stimuli. Evidence for the converse effect (backward/unpleasant) has also been found but tends to be weaker. Theoretically, the effects have often been taken as support for the notion that emotions activate motivational (behavioral) tendencies, which in turn shows up in whole body postural adjustments, often with a clear directional (forward/backward) component.

The above two studies by the Miles group were original, and seem to have led to clear-cut postural effects, providing compelling evidence for the notion that abstract thought is embodied in body posture. However, several empirical and methodological issues remain to be answered.

First, Miles et al. (2010) asked subjects to picture themselves four years in the past, or (in another group of subjects) to picture themselves four years in the future. In their Discussion, Miles et al. (2010) suggested that future research should look at whether the effect would be modulated by 'temporal distance' (p. 223), so that less distant events would perhaps lead to smaller postural effects compared to more distant events. Hence, the first aim of our study was to test this hypothesis by directly comparing mental imagery involving four years in the past and the future, and mental imagery involving four days in the past and the future.

Second, the interpretation by Miles et al. (2014) regarding postural directional effects of imagining social encounters may not be conclusive, as alternative explanations are possible. For instance, it may be asked whether the effects of emotion were due to the valence (i.e., pleasantness), or the motivational properties of the imagery events. That is, thinking of a good friend not only elicits feelings of warmth and positive affect, but also the tendency to approach that person and shake his hand. Therefore, in the current study, we asked participants to think of pleasant and unpleasant events in their life (potentially involving social interaction), instead of direct (imagined) face-to-face social encounters, as in Miles et al. (2014). Posturographic studies (e.g., Hillman et al., 2004; Stins & Beek, 2011) found that visual stimuli with affective content can have a direct effect on postural parameters related to approach-avoidance tendencies. In keeping with this literature, we asked whether merely *thinking* of something pleasant or unpleasant can already induce directional changes in body posture.

To answer these questions we recorded and analyzed postural changes by means of a force plate as a function of the content of mental images. That is, in contrast to the studies by Miles and colleagues, we decided to use a different recording device. In Miles et al. (2010) and Miles et al. (2014), postural excursions were measured by recording the position of a single marker attached to the knee, using a magnetic motion-tracking system. A potential disadvantage of this method is that not only forward bodily leaning will result in forward displacement of the knee marker, but also simple knee flexion (that is, without postural shift). So strictly speaking we don't know whether imagery resulted in whole-body postural sway (as the authors suggested), or in subtle changes in knee angle. To this end, we decided to record variations in the body center of pressure using a force plate. Changes in the point of application of the ground reaction force are tightly coupled to changes in the position of the body center of mass, thereby providing a more reliable method to quantify bodily lean.

2. Method

2.1. Participants

Thirty-two participants (16 males; 16 females; mean age = 20.3 years; SD = 1.4) volunteered to take part in the experiment. Participants had normal or corrected-to-normal vision and were naive as to the purpose of the study. All participants provided informed consent prior to experimentation, and the experiment was approved by the ethical committee of the Faculty of Human Movement Sciences, VU University Amsterdam.

2.2. Apparatus

To measure postural sway, participants stood on a custom-made strain gauge force plate (1×1 m) that sampled at frequency of 100 Hz. The force plate consisted of eight force sensors. Four sensors measured the forces in the z direction, two in the x direction and two in the y direction. These 8 signals were automatically converted into a center-of-pressure time series, separate for the medio-lateral (ML) and the anterior-posterior (AP) direction. At the end of each trial participants verbally provided a vividness rating on how well they were able to mentally imagine that particular event for the duration of the trial. Values could range from 1 (no imagery at all) to 6 (very clear and vivid imagery). For practical reasons the experiment was always supervised and run by two experimenters (LH and RJ).

2.3. Procedure

Participants were asked to take off their shoes, step onto the middle of the force plate, and adopt a relaxed upright standing posture, with the arms hanging beside the body. Next, the lights were dimmed and participants were asked to close their eyes, and to mentally imagine one of twelve events (see below) that were read aloud each time by the experimenter. Participants were asked to imagine each event for a duration of 30 s, which was also the recording duration of the COP trace. At the end of each trial participants verbally provided a vividness rating on how well they were able to mentally imagine that particular event for the duration of the trial. More precisely, during the neutral trials we asked participants how well they were able to form a mental picture, with values ranging from 1 (no imagery at all) to 6 (very clear and vivid imagery). During the pleasant trials values ranged from 1 (not very pleasant) to 6 (very pleasant), and during the unpleasant trials values ranged from 1 (not very unpleasant) to 6 (very unpleasant). Thus, the values in these trials reflect the felt intensity of the self-generated emotion scenario. Each value was written down by the experimenter and later entered into the computer. Note that we did not explicitly instruct participants to form a *visual* image of the event, neither did we ask them to rate the *visual* vividness of the images. Instead, we simply asked them how well they were able to generate and uphold a mental representation of a particular event (which may or may not have been visual in nature). For practical purposes, we refer to the subjective ratings as vividness ratings, even though the term 'vividness' has strong connotations with visual imagery.

2.4. Imagery events

Four trials involved imagery of a typical day in the past and in the future; involving either four days or four years. Note that trials involving imagery four years in the past and in the future are identical to the ones tested by Miles et al. (2010). Note also that these trials did not involve a particular emotion, so we labelled these as 'neutral'.

Four additional trials involved imagery of a (real) past emotional event. The past events were divided into pleasant and unpleasant events. The two pleasant scenarios were related to (1) school or work, e.g., a fun day out, and (2) a party; the two unpleasant scenarios were associated with (3) school or work, e.g., a bad grade or evaluation, and (4) a funeral. The final four trials involved imagery of a (potential) future emotional event. The future events were likewise divided into pleasant and unpleasant events. The two pleasant scenarios were related to (1) school/work, e.g., obtaining a sought-after degree, and (2) a future party, and the two unpleasant scenarios to (3) school/work, e.g., potentially losing a job, and (4) an upcoming funeral of someone who is still alive. All these eight trials involved events four years in the past or four years in the future.

All twelve trials are displayed in Table 1.

2.5. Randomization

The experiment was divided in two blocks of trials; six involving imagery of a past event and six involving imagery of a future event. Block order was counter-balanced across participants. Each block always started with the two neutral trials, with duration (4 days; 4 years) randomized. These neutral trials were then randomly followed by two pleasant or two unpleasant trials.

2.6. Measures

In keeping with previous studies we only analyzed anterio-posterior (AP) displacements of the COP, and not the medio-lateral component of sway. The AP time series were first filtered using a 5-point moving average, to remove high-frequency components from the signal. Next, the time series were aligned so that they all started from a common origin, namely 0. As a result, positive values represent displacements in the forward direction, and negative values represent displacements in the backward direction.

2.7. Data analyses

We performed three separate analyses. Our overall approach involved applying a number of linear fits (using the *polyfit* function in Matlab) to the AP time series, and testing whether, and to what extent, the slope values of the fitted lines varied as a function of imagery. All slope values are expressed as mm per s.

First, we aimed at directly comparing our results to those of Miles et al. (2010). To this end, we applied a linear fit through the first 15 s of Trials 1 and 3. We expected a negative value of the slope for Trial 1 (representing backward lean when thinking of the past) and a positive value for Trial 3 (representing forward lean when thinking of the future). Slope values were compared using a paired samples *t*-test.

Our second analyses aimed at testing whether mental imagery of four years (past or future) would lead to stronger effects on postural AP displacements than imagery of four days. Since we did not know in advance whether, and if so, where in the time series postural effects would show up, we took the following approach: We first fitted a straight line through the entire 30 s time series, and we entered the resultant slope values of the four neutral trials (trials 1–4 in Table 1) in a repeated-measures analysis of variance (ANOVA), with the following factors: (time: future/past) × (duration: 4 days/4 years). Next, we divided the 30-s time series into three 10-s segments, and we fitted a straight line through each segment. Our reasoning for time binning the data was that it could be the case that the COP would 'wander off' only in the first part of the imagery trial (and later return to baseline), because a continuous displacement in the same direction would inevitably lead to a loss of stability, which would require postural adjustments in the opposite direction in order to prevent a fall. We then analyzed the slope values using an ANOVA with the following factors: (time: future/past) × (duration: 4 days/4 years) × (segment: 1–10 s, 11–20 s, 21–30 s).

Our final analysis asked whether effects of time (future and past) and valence are additive or whether they interact. To this end, we analyzed the emotion trials (trials 5–12 in Table 1). We first averaged the slope values across each of the two scenarios. As above, we calculated slopes for the entire 30 s time series, and additionally for the three 10-s time segments,

Table 1
List of all 12 imagery trials.

Trial nr.	Time	Valence	Scenario	Instruction: try to imagine ...
1[a]	4 years past	Neutral	None	.. a typical day in your past
2	4 days past	Neutral	None	.. a typical day in your past
3[a]	4 years future	Neutral	None	.. a typical day in your future
4	4 days future	Neutral	None	.. a typical day in your future
5	4 years past	Pleasant	School/work	.. a pleasant event involving school/work, such as a school trip
6	4 years past	Pleasant	Party	.. a pleasant event involving a party, such as receiving a nice gift
7	4 years future	Pleasant	School/work	.. a pleasant event involving school/work, such as obtaining a diploma or receiving a bonus
8	4 years future	Pleasant	Party	.. a pleasant event involving a party, such as receiving a nice gift
9	4 years past	Unpleasant	School/work	.. an unpleasant event involving school/work, such as receiving a bad grade
10	4 years past	Unpleasant	Funeral	.. an unpleasant event involving a funeral
11	4 years future	Unpleasant	School/work	.. an unpleasant event involving school/work, such as receiving a bad grade or losing your job
12	4 years future	Unpleasant	Funeral	.. an unpleasant event involving a funeral

[a] Trials 1 and 3 are identical to the ones employed by Miles et al. (2010).

yielding again two ANOVAs: a 2 (time) × 2 (valence: pleasant/unpleasant) ANOVA, and a time × valence × segment (1–10 s, 11–20 s, 21–30 s) ANOVA.

For all analyses the alpha-level was set at 0.05. Effect sizes of the ANOVA are reported as partial eta-squared (η_p^2).

3. Results

The data of one (female) participant was discarded because halfway the experiment she was feeling unwell, and the experiment was halted. Means slope values for all conditions are shown in Table 2.

The *t*-test revealed no significant difference between Trials 1 and 3, $t(30) = .416$, $p = .681$. The slope values for Trials 1 (four years past imagery) and 3 (four years future imagery) were .0015 and .0010, respectively, indicating a very mild forward displacement of the COP in both cases. Grand averaged COP wave forms for both conditions are shown in Fig. 1. Note that this non-significant result cannot be taken to support the null hypothesis. However, using Bayesian statistics we can at least quantify the relative predictive success of the null hypothesis, relative to the alternative hypothesis. Following Dienes (2014) we calculated the Bayes factor (BF), using the BayesFactor package in R. We adopted the default cauchy prior of .707. As a rule of thumb, a Bayes factor greater than 3 indicates substantial evidence for the alternative hypothesis; a Bayes factor smaller than 1/3 indicates substantial evidence for the null; and intermediate values indicate that there is little support for either hypothesis given the data (Dienes, 2014). With respect to the present dataset, we found a Bayes factor of .207. This signifies that the null is 4.83 times more likely than the alternative hypothesis, which indicates that the strength of the evidence favoring the null should be considered substantial (Dienes, 2014). In other words, past imagery and future imagery lead to statistically indistinguishable COP profiles.

We additionally reasoned that the lack of an effect could be due to individual differences in imagery ability. To this end, we divided the group of subjects in two groups based on a median split of vividness ratings for Trials 1 and 3 (combined), yielding a 'high' and 'low' vividness group. We next performed the same *t*-test and Bayesian analysis separately for both groups, but again no significant differences between future and past imagery showed up (high: $t = .39$, BF = .27; low: $t = .19$, BF = .26). We also checked whether the lack of effect could be due to order effects. After all, half the subjects started with imagery of past events, followed by a block of future events, whereas for the other half of the subjects the order was reversed. It could be that our within-subjects design (in contrast to the between-subjects design of Miles et al. (2010)), somehow reduced the effect of imagery on posture. To this end we directly compared slope values of past imagery events - obtained in the beginning of the experiment- in half of the subjects with the slope values of future imagery events of the alternate subset of subjects (again obtained in the beginning of the experiment). This was done using an unpaired samples *t*-test. The analysis revealed that the difference in slope values was far from significant ($t = .33$, BF = .35). So, after extensive testing, we must conclude that imagery of past events versus imagery of future events had no discernible influence on spontaneous forward/backward postural displacements.

The first ANOVA, aimed at testing postural effects of duration (4 days vs 4 years), revealed no main or interaction effects (all F-values < 1). When the analysis was performed with segment as additional factor, the three-way time × duration × segment interaction was significant, $F(2,60) = 3.28$, $p = .045$, $\eta_p^2 = .098$. To explore this interaction we performed separate time by duration ANOVAs, for each of the three time segments. This revealed a time × duration interaction only for the second time segment, i.e., from 11 to 20 s, $F(1,30) = 10.17$, $p = .003$, $\eta_p^2 = .253$. Further exploration of this interaction using paired-samples *t*-tests revealed that the COP slopes for past and future only differed for the 4 days duration, $t(30) = 2.76$, $p = .01$, and not for the 4 years duration. The means of the slopes for past and future were .0035 and −.0019, respectively.

The second ANOVA, aimed at testing postural effects of valence, revealed no effects involving time or valence. Importantly, the predicted effect of valence was far from significant, $F(1,30) = .64$, $p = .43$, $\eta_p^2 = .021$. In order to further examine this null effect we calculated the Bayes factor for the direct contrast between pleasant and unpleasant scenarios. To this end, we first created a new variable involving the average slopes of the two pleasant conditions (averaged over time), and a new variable involving the average slopes of the two unpleasant conditions. The paired *t*-test between the conditions

Table 2
Mean slope values for all conditions, expressed as mm/s, together with mean vividness ratings (+standard errors of the mean).

Trial	Segment 1 (1–10 s)	Segment 2 (11–20 s)	Segment 3 (21–30 s)	Total (1–30 s)	Vividness/intensity
4 years past, Neutral	0.30 (1.18)	0.66 (1.14)	1.36 (1.16)	1.04 (0.49)	4.4 (0.18)
4 days past, Neutral	1.91 (1.44)	3.47 (1.59)	0.14 (1.04)	0.70 (0.52)	4.4 (0.21)
4 years future, Neutral	1.12 (1.33)	2.43 (1.17)	1.69 (1.18)	1.21 (0.46)	3.5 (0.21)
4 days future, Neutral	4.37 (2.05)	−1.98 (1.27)	1.70 (1.21)	1.04 (0.64)	4.4 (0.17)
4 years past, Pleasant	0.12 (0.95)	1.53 (0.81)	0.71 (0.87)	0.68 (0.36)	4.5 (0.13)
4 years past, Unpleasant	1.37 (0.79)	1.07 (1.07)	0.03 (0.86)	0.56 (0.45)	3.6 (0.16)
4 years future, Pleasant	0.47 (0.75)	0.40 (0.91)	−1.62 (1.02)	−0.06 (0.44)	4.5 (0.13)
4 years future, Unpleasant	1.88 (1.21)	1.79 (0.93)	−1.26 (1.06)	0.83 (0.57)	4.0 (0.19)
4 years, Pleasant	0.30 (0.69)	0.96 (0.50)	−0.45 (0.63)	0.31 (0.25)	
4 years, Unpleasant	1.62 (0.77)	1.43 (0.59)	−0.62 (0.73)	0.70 (0.37)	

Note: Positive slope values represent forward leaning, and negative slope values represent backward leaning. To increase legibility all slope values have been multiplied by 1000. The bottom two rows represent slope values for pleasant and unpleasant imagery, averaged over time (future and past).

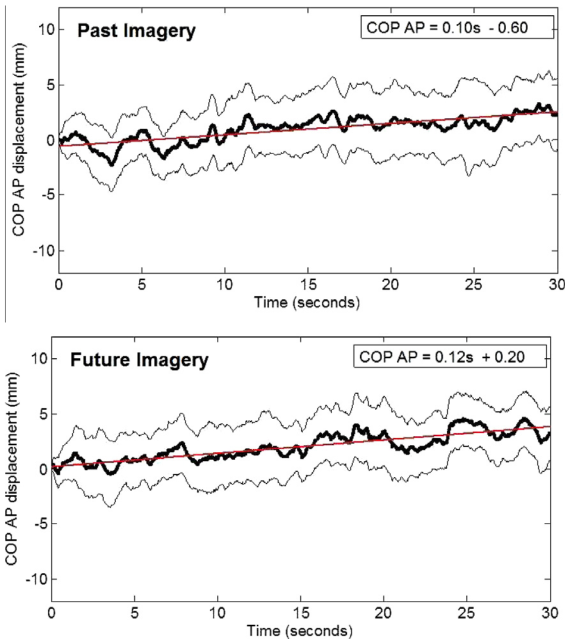

Fig. 1. Grand averaged wave forms of the COP trace (bold line), plus 95% confidence intervals. The red line represents the linear fit through the entire 30-s time series. Top panel: four years past imagery. Bottom panel: four years future imagery. Both graphs are characterized by mild forward displacement of about 2 mm over the entire time course. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

revealed the expected absence of significance, $t(30) = -0.80$, $p = .43$. The Bayes factor was .26. This signifies that the null is 3.85 times more likely than the alternative hypothesis, thus indicating substantial evidence favoring the null. As a final analysis, we again divided the participants in two groups based on the felt intensity of the emotion scenarios, i.e., a high group (very pleasant and/or very unpleasant emotions) and a low group (not very emotional experiences). The above analyses were then run for the high and low intensity group as between subjects factor, as was done above, but again we found no differential effects involving this variable.

When the analysis was performed with segment as additional factor only a main effect of segment was observed, $F(2,60) = 3.26$, $p = .045$, $\eta_p^2 = .098$. The first two segments (i.e., 1–20 s) were characterized by small positive slope values, indicating forward lean, .001 and .0012, respectively, whereas the third segment (21–30 s) had a negative COP slope of $-.0005$, indicating backward lean.

4. Discussion

The aim of this study was to examine whether mental imagery of abstract items (related to time and related to affect) affected center-of-pressure displacements during upright quiet standing. Based on earlier work (Miles et al., 2010, 2014) we predicted that imagery content would lead to specific forward or backward displacements of the body COP. If so, this would lend support to the notion that cognitive activity, such as the representation of abstract concepts, can be grounded in the human postural control system. More specifically, it would provide evidence for the notion that time and valence are mentally represented along a spatial (forward-backward) dimension, and that activation of such representations leads to motoric changes. The choice to investigate changes in postural orientation was motivated by the observation that, under normal circumstances, quiet standing involves configuring the body such that it is perfectly aligned along the gravitational axis, i.e., in a vertical orientation. Even though we can perform this motor task with very little effort, the upright standing human body is mechanically highly unstable, and subtle variations in the COP are indicative of postural perturbations. In our study the postural perturbations were of a cognitive nature (mental activity involving events of one's own life span) with a clear directional component. If such mental activity induces corresponding postural changes, this would mean that the sensory-motor system embodies abstract concepts (Gallese & Lakoff, 2005).

We first tried to replicate the basic finding of Miles et al. (2010), by investigating changes in the body COP. Our results were clear cut: we found no evidence of center-of-pressure modifications as a function of 'mental time travel'. Both thinking about the past and thinking about the future led to a negligible postural increment in the forward direction. The only significant effects we found appeared when we segmented the COP data into time bins, of 10 s each. These effects could reflect relatively uninteresting phenomena regarding unintended low frequency postural excursions in a particular direction, followed by compensatory movements in the opposite direction to prevent loss of stability. However, we consider these effects chance effects and of little importance to the current topic.

Our main research question involved putative effects of past vs future imagery on body posture, for which we found no evidence. The results of our Bayesian analysis in fact provide substantial evidence for the null hypothesis, which is in stark contrast to Miles et al. (2010). The obvious question is why our results are so divergent. There are admittedly small differences between the setups; for example, Miles et al. (2010) adopted a between-subjects design (with 10 subjects performing past imagery, and 10 subjects performing future imagery), whereas we adopted a within-subjects design with 31 subjects. A potential advantage of a between-subjects design is that order effects (e.g., changes in motivation) do not play a role. Yet, first, we counterbalanced for order and second, a separate analysis on only the early trials revealed no evidence of an effect of time on posture. Another difference concerns the recording device; Miles et al. (2010) recorded the position of a knee marker, whereas we recorded the position of the COP using a force plate. As stated in Section 1, this latter method has the advantage that changes in body position are more accurately recorded, i.e., unaffected by knee angle. However, we see no reason why thinking of the past would lead subjects to extend their knee (resulting in backward displacement of the marker), and why thinking of the future would lead subjects to flex their knee (resulting in forward displacement of the marker). Finally, there may have been subtle differences in subject characteristics, or differences in procedure, such as the exact phrasing of the instructions. But if this were the case, this would mean that the effect of mental time travel, as reported by Miles et al. (2010) occurs only in very specific, unknown, circumstances, and hence may not be generalizable to a broader spectrum of circumstances.

Concerning our first research question as to whether thinking about the past and future with a duration of four years would lead to stronger effects than four days, our results revealed that neither duration had a discernible effect on posture. Somewhat surprisingly, we did find an effect of time when the duration was four days, and only in the second recording interval (11–20 s). Admittedly, there was a difference between past and future imagery, but the effect was opposite to what we expected; past imagery led to greater forward displacement than future imagery, but again the effect was very small. At present we have no explanation for the effect; it could have been simply due to chance. However, at the very least it again implies that we could not replicate effects of mental time travel on posture.

Our second question was whether thinking of pleasant vs unpleasant items would lead to forward or backward displacements of the COP, respectively, reminiscent of 'approach-avoidance' effects (e.g., Hillman et al., 2004). Participants were asked to imagine various pleasant and unpleasant events (in the past or in the future). We gave only very general hints as to the exact nature of imagery, so that participants were free to incorporate their own personal likes and dislikes into the imagery scenarios. Our results yielded no evidence for an effect of valence on spontaneous postural approach-avoidance behaviors. The results of the Bayesian analysis provided support for the null. This is in contrast with Miles et al. (2014) who found clear effects of imagining positive and negative social encounters on posture. There are (at least) two differences between their study and ours. First, Miles et al. (2014) found that the effect was dependent on vantage point: only from a first-person (labelled 'field') perspective did postural approach-avoidance effects show up, and not from a third-person ('observer') perspective. In our study, however, no reference was made to vantage point, so it could have been the case that participants generally adopted either one of the two, or both. We would like to point out that our subjects reported, on average, quite acceptable vividness ratings for the imagery trials (see Table 1), so that we feel safe to conclude that they must have engaged in some form of mental activity as instructed. Second, and more important, the social encounters envisioned in the Miles et al. (2014) study not only had affective properties (i.e., being positive or negative); they also had clear motivational properties, in that some encounters would prime one to approach (when seeing a friend) and others to withdraw (seeing a tall stranger). We therefore deem it reasonable that the effects reported by Miles et al. (2014) might in fact be related to action tendencies, invoked by the (imagined) social interactions, and resulting in priming and partial execution of the associated motor program. In our experiment, by contrast, there were admittedly events with a clear social dimension (party, funeral, etc.), but they were not framed as direct face-to-face encounters of various natures. In order to further investigate the nature of the reported postural modifications, future studies should try to directly compare affective and motivational imagery scenarios.

To conclude, we found neither effects of mental time travel nor of thinking of (un)pleasant events on postural forward or backward motions. Thus, our data does not provide support for the theoretical notion that abstract representations are coupled to whole-body postural effects. Even though we typically represent the progression of time, and the experience of valence, along a spatial continuum, such representations do not seem to be embodied or –at least not always – result in changes in postural orientation. In contrast, the extant literature on motor imagery (see Section 1) suggests that balance can be reliably disturbed by imagining motoric activities; at least when the activities involve a clear postural component, such as jumping. Therefore, we recommend that future studies that investigate whether abstract thought is grounded in body posture should control for unintended effects of motor imagery. In addition, the putative effects of imagery as studied here, and by the Miles group, rely heavily on autobiographic memory, the contents of which of course vary greatly among individuals. For example, some individuals may have had their share of misfortune in their lives, whereas others may hardly have given thought to their own future course of life. In order to control for this source of variation, future studies could consider presenting subjects with more clear and well-defined imagery scenarios (e.g., Stins et al., 2015), as a testing ground for embodied cognition effects on body posture.

Ethical approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

References

Barsalou, L. W. (2008). Grounded cognition. *Annual Review of Psychology, 59*, 617–645.
Boulton, H., & Mitra, S. (2013). Body posture modulates imagined arm movements and responds to them. *Journal of Neurophysiology, 110*, 2617–2626.
Bouman, D., Stins, J. F., & Beek, P. J. (2015). Arousal and exposure duration affect forward step initiation. *Frontiers in Psychology, 6*, 1667.
Decety, J., Jeannerod, M., Durozard, D., & Baverel, G. (1993). Central activation of autonomic effectors during mental simulation of motor actions in man. *Journal of Physiology, 461*, 549–563.
Dienes, Z. (2014). Using Bayes to get the most out of non-significant results. *Frontiers in Psychology, 5*, 781.
Frazier, E. V., & Mitra, S. (2008). Methodological and interpretive issues in posture-cognition dual-tasking in upright stance. *Gait & Posture, 27*, 271–279.
Gallese, V., & Lakoff, G. (2005). The brain's concepts: The role of the sensory-motor system in conceptual knowledge. *Cognitive Neuropsychology, 22*, 455–479.
Grangeon, M., Guillot, A., & Collet, C. (2011). Postural control during visual and kinesthetic motor imagery. *Applied Psychophysiology & Biofeedback, 36*, 47–56.
Guillot, A., Lebon, F., Rouffet, D., Champely, S., Doyon, J., & Collet, C. (2007). Muscular responses during motor imagery as a function of muscle contraction types. *International Journal of Psychophysiology, 66*, 18–27.
Hartmann, M., Martarelli, C. S., Mast, F. W., & Stocker, K. (2014). Eye movements during mental time travel follow a diagonal line. *Consciousness & Cognition, 30*, 201–209.
Hartmann, M., & Mast, F. W. (2012). Moving along the mental time line influences processing of future related words. *Consciousness & Cognition, 21*, 1558–1562.
Hillman, C. H., Rosengren, K. S., & Smith, D. P. (2004). Emotion and motivated behavior: Postural adjustments to affective picture viewing. *Biological Psychology, 66*, 51–62.
Miles, L. K., Christian, B. M., Masilamani, N., Volpi, L., & Macrae, C. N. (2014). Not so close encounters of the third kind: Visual perspective and imagined social interaction. *Social Psychology and Personality Science, 5*, 558–565.
Miles, L. K., Nind, L. K., & Macrae, C. N. (2010). Moving through time. *Psychological Science, 21*, 222–223.
Oishi, K., & Maeshima, T. (2004). Autonomic nervous system activities during motor imagery in elite athletes. *Journal of Clinical Neurophysiology, 21*, 170–179.
Rodrigues, E. C., Lemos, T., Gouvea, B., Volchan, E., Imbiriba, L. A., & Vargas, C. D. (2010). Kinesthetic motor imagery modulates body sway. *Neuroscience, 169*, 743–750.
Stins, J. F., & Beek, P. J. (2011). Organization of voluntary stepping in response to emotion-inducing pictures. *Gait and Posture, 34*(2), 164–168.
Stins, J. F., Schneider, I. K., Koole, S. L., & Beek, P. J. (2015). The influence of motor imagery on postural sway: Differential effects of type of body movement and person perspective. *Advances in Cognitive Psychology, 11*, 77–83.
Ulrich, R., Eikmeier, V., de la Vega, I., Fernández, S. R., Alex-Ruf, S., & Maienborn, C. (2012). With the past behind and the future ahead: Back-to-front representation of past and future sentences. *Memory and Cognition, 40*, 483–495.