Creativity Research Journal

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/hcrj20

On the Generalizability of the Bodily State Effect on Creativity

Yanyun Zhou & Bernhard Hommel

To cite this article: Yanyun Zhou & Bernhard Hommel (2023): On the Generalizability of the Bodily State Effect on Creativity, Creativity Research Journal, DOI: 10.1080/10400419.2023.2171339

To link to this article: https://doi.org/10.1080/10400419.2023.2171339

Published online: 09 Feb 2023.

CREATIVITY RESEARCH JOURNAL
https://doi.org/10.1080/10400419.2023.2171339

On the Generalizability of the Bodily State Effect on Creativity

Yanyun Zhou[a] and Bernhard Hommel[b,c]

[a]College of Education Science and Technology, Nanjing University of Posts and Telecommunications, Nanjing, China; [b]Cognitive Neurophysiology, Department of Child and Adolescent Psychiatry, Faculty of Medicine, TU Dresden, Dresden, Germany; [c]Department of Psychology, Shandong Normal University, Jinan, China

ABSTRACT
Previous studies found that bodily states have an impact on divergent thinking, but it remains to be seen how generalizable this effect could be, how exactly it depends on cognitive control, and whether similar effects can be found on convergent thinking. To address these questions, we examined the bodily state effect on divergent thinking, convergent thinking, and cognitive control in two experiments. In Experiment 1, participants performed the Alternate Uses Task, the Remote Associates Task, and an auditory Stroop task under one of the three bodily states: sitting, standing, or roaming. In Experiment 2, participants completed the three tasks while standing and while roaming. Results showed that bodily state had no significant effect on divergent thinking and the Stroop effect, while roaming shorten the reaction times (Experiment 1) and increased accuracy (Experiment 2) comparing with sitting or standing in the convergent thinking task. Bayesian analysis provided strong or moderately strong evidence for the null hypothesis for these effects. Taken together, the present experiments showed no stable bodily state effect on divergent thinking or convergent thinking and Stroop effect. Possible explanations for the discrepancy between the current results and those reported in previous studies were discussed.

ARTICLE HISTORY
Received August 24, 2022

Introduction

Previous studies found that bodily postures, such as lying, sitting, or standing, can have an impact on cognitive activities. The studies by a group of researchers at the University of California have presented the most systematic exploration of such effects (Cann, 1990; Vercruyssen & Simonton, 1988; Woods, 1981). Woods (1981) reported that standing up could significantly improve the information processing speed of elderly (60–70 years old) people in both a simple reaction time (RT) and two-choice visual RT, as compared with lying or sitting. Old and unfit individuals benefited most from this posture effect, which was not observed among the young adults (18–28 years old). Following Woods' study, Vercruyssen and Simonton (1988) found further support for the posture effect (standing speeding up the response), which became more evident if the task demanded more sustained attention but was only seen in male participants. Cann (1990) included all the variables involved in previous studies and found that task difficulty could also moderate the effect. The results revealed that for both older (mean age 71 years) and younger (mean age 25 years) adults, RT was significantly shorter in the standing condition than that in the lying or sitting conditions, but only with moderate task difficulty. In more difficult tasks, standing instead impaired the performance of the older adults. In contrast, Lipnicki and Byrne (2005) found that people performed 3.1 s faster when lying than standing in an anagram solving task, while there was no difference in solving mental arithmetic problems between standing and supine. Overall, these studies show that posture can speed up participants' responses in some tasks, but this effect is limited by many factors such as age, gender, and task difficulty.

Recent studies focused on the effect of bodily states like slow walking on creativity (e.g., Kuo & Yeh, 2016; Oppezzo & Schwartz, 2014; Zhou, Zhang, Hommel, & Zhang, 2017). For example, in four studies, Oppezzo and Schwartz found that, compared with sitting (either on a chair in a room or in a wheelchair outside on the campus), walking along a predetermined pathway at the campus or treadmill improved participants' performance in the Alternate Uses Task (AUT) or Barron's symbolic equivalence task, suggesting that walking could promote divergent thinking. However, in this study, walking was always constrained (either walking on a treadmill or walking along a fixed path), and the

CONTACT Yanyun Zhou yyzhou@link.cuhk.edu.hk College of Education Science and Technology, Nanjing University of Posts and Telecommunications, Nanjing, China

authors did not provide any possible mechanism for their findings. To extend these observations, Zhou et al. (2017) conducted two experiments to examine how divergent thinking could be influenced by bodily states, including roaming (free walking, walking unconstrainedly in a vacant room), non-roaming (constrained walking following a predetermined path), standing, sitting, and lying. They found a bodily state effect on divergent thinking: roaming, as compared with non-roaming, did facilitate divergent thinking.

Embodied metaphor explanation of the bodily state effect on divergent thinking

Some researchers attribute the promoting effect of walking on creativity to the influence of conceptual metaphors (Kuo & Yeh, 2016; Leung et al., 2012; Oppezzo & Schwartz, 2014). Conceptual metaphor theory is one of the important theoretical bases in embodied cognition (IJzerman & Koole, 2011; Landau, Meier, & Keefer, 2010). Based on this theory, there is a metaphoric relationship between physical experience and mental activities; for example, physically moving around could be metaphorically related to mentally moving around (Leung et al., 2012). Along these lines, engaging in creativity-related metaphors, such as tracing fluid drawing (to trace the lines with curvature) as compared with tracing a non-fluid drawing (to trace the lines without curvature) (Slepian & Ambady, 2012), assuming postures involving both hands (creativity being metaphorically associated with bilateral physical orientations) versus postures involving only one hand, or sitting outside of a box (associated with the "think out of box" metaphor) instead of sitting inside a box, can be all expected to promote creativity. According to this embodied conceptual-metaphor approach, walking elicits fluid movements in body and activates fluid movements in mind, so that roaming could facilitate creativity more than walking along a fixed path (Kuo & Yeh, 2016; Leung et al., 2012).

The embodied conceptual-metaphor explanation could accommodate Experiment 1′s findings in Zhou et al. (2017). Participants showed better divergent thinking in the walking condition than in the standing condition, and better performance in the roaming condition than in the non-roaming condition, because roaming activated the metaphorically related changes in mind and facilitate the creative behaviors. In Experiment 2, Zhou et al. adopted a falsification method to test this explanation against a control depletion account, that we will turn to in the next paragraph. In addition to the observation on how two walking conditions and standing condition were distinguished from each other on the impact of divergent thinking, the study further compared the effect of bodily state of lying, sitting, and standing on two creativity tasks: AUT (Experiment 2A) and figural combination task (Experiment 2B). Results repeatedly showed that standing could significantly enhance people's creative performance as compared with sitting and lying. Since none of these three conditions involved movement, this result could not be explained by the metaphorical relationship with physical movement.

Control-depletion explanation on the bodily state effect on convergent and divergent thinking tasks

As an alternative, Zhou et al. (2017) considered an account in terms of ego depletion. Depletion of cognitive control resources might facilitate divergent creativity by de-focusing attention. Previous works showed that depleting resource by engaging in a control-demanding task might defocus attention, which could in turn would support divergent thinking (Baumeister, 1998; Radel, Davranche, Fournier, & Dietrich, 2015). Since the resource for self-control is limited (Muraven, Tice, & Baumeister, 1998), if a portion of cognitive resource is devoted to one self-control task, less could be available for others (Muraven & Baumeister, 2000). For example, certain gaits or postures can be assumed to consume more cognitive resources, so that fewer resources could be devoted to the cognitive task (Lacour, Bernard-Demanze, & Dumitrescu, 2008; Lacour & Borel, 1993). When a dual task involves both physical and cognitive activities, participants have to distribute the limited attention resources to two activities, which would induce defocused attention. Some cognitive tasks, such as convergent thinking, may require focused attention and strong top-down control, so that performance in such tasks may be impaired by resource depletion. Divergent thinking, however, is likely to benefit from a less strong focus of attention (Finke, Ward, & Smith, 1992; Glazer, 2009; Gruszka & Necka, 2002; Howard-Jones & Murray, 2003; Martindale, 1995, 1999; Smith, 1995; Zabelina & Robinson, 2010), so that having fewer resources might be helpful.

Requirements of cognitive resource depend on the type of physical states or activities (Beurskens & Bock, 2013; Kerr, Condon, & McDonald, 1985; Lajoie, Teasdale, Bard, & Fleury, 1993; Woollacott & Shumway-Cook, 2002). Previous studies found that standing requires more attentional resources than sitting (Lajoie et al., 1993; Lajoie, Teasdale, Bard, & Fleury, 1996), and walking depleted more resources to keep balance than standing (Lajoie et al., 1993, 1996; Lindenberger, Marsiske, & Baltes, 2000). Thus, participants were slower to complete cognitive tasks in the walking condition than in the sitting condition (Lajoie et al., 1993) and produced more errors in a recall task (Lindenberger et al., 2000) and subtraction task (Srygley, Mirelman, Herman, Giladi, & Hausdorff, 2009) in the walking condition than in the standing or sitting condition. This suggests that more "active" bodily states or physical activities imply more defocusing.

In contrast to tasks that rely on focused attention, novel idea generation might benefit from walking, say (vs. standing): more active bodily state tasks (e.g., walking) would tend to overload top-down control more, and thus facilitate divergent thinking. In Zhou et al. (2017), standing could have promoted the generation of original ideas more than lying or sitting, and walking (roaming and non-roaming) might have improved creative performance more than standing. However, Rosenbaum, Mama, and Algom (2017) found that standing (vs. sitting) shortened RT in a Stroop task and reduced the Stroop effect (RTs for the incongruent condition minus RTs for the congruent condition), suggesting that standing might strengthen (rather than weaken) cognitive control. This provided evidence against Zhou et al.'s (2017) depletion account. In addition, Zhou et al.'s (2017) argument that better performance in the roaming condition than in the constrained walking condition would fit with a depletion account if one considers that free-choice tasks are more demanding than forced-choice tasks (Berlyne, 1957) can be argued to have a weakness. It has been suggested that a curved-path walking condition (constrained walking as in Zhou et al.) requires more cognitive resources to navigate the direction and keep balance than straight-path walking (Beurskens & Bock, 2013; Courtine & Schieppati, 2003; Hess, Brach, Piva, & VanSwearingen, 2010; Lowry, Brach, Nebes, Studenski, & VanSwearingen, 2012). From a depletion account, one would thus expect better performance in divergent thinking in the constrained walking condition than with unconstrained walking, which is not what was found.

As these considerations raised out in the feasibility of a depletion account, we aimed to test this account more directly in the present study, in addition to the attempt to generalize the previously observed effect to other creativity tasks. To provide a more direct test, we also included an auditory Stroop task in each bodily state condition to provide a direct measurement of cognitive control performance. To generalize previous effects, we did not only consider divergent thinking but also included a convergent-thinking task. Both tasks can be considered to tap into human creativity, but processes underlying divergent and convergent thinking have been assumed to differ (Guilford, 1967) and demonstrated to be sensitive to different manipulations and situational factors (e.g., Hommel & Colzato, 2017). In particular, convergent thinking is commonly assumed to be closer to cognitive control processes, so that a convergent task might be considered a mirror image of divergent tasks. Accordingly, performance on convergent tasks might be impaired, rather than enhanced by cognitive depletion (Radel et al., 2015).

To summarize, we included three tasks, AUT for the measurement of divergent thinking, the Remote Associates Task (RAT) for the measurement of convergent thinking, and the auditory Stroop task for the measurement of cognitive control. In Experiment 1, we used a between-participants design, in which participants performed the three tasks in a sitting, standing, or roaming condition. In Experiment 2, we used a within-participants design, in which all participants performed the three tasks in both standing and roaming conditions. We hypothesized that the bodily state would have different effects on divergent thinking and convergent thinking. While walking should promote divergent thinking, it might hinder convergent thinking. If embodied metaphor played an important role, roaming would facilitate divergent thinking, while there would be no significant difference between standing and sitting, and no significant difference between conditions for convergent thinking task and the Stroop task. In contrast, if depletion of cognitive control resources would be relevant, roaming would cause the largest Stroop effect, followed by the standing condition and finally the sitting condition. In the divergent thinking task, roaming should be best, and standing be better than sitting.

Norming study

This study aimed to develop the set of stimuli for the RAT being appropriate for our Chinese participants.

Methods

Participants

Thirty-six students (10 males) from a University in China volunteered to participate in the difficulty rating task.

Stimuli

We first created 115 triplets (each with a solution that was associated with all three items in the triplet) based on those used in Chen et al. (2012) and chose the items based on the following criteria: First, we only included triplets with nouns and excluded those with verb and adjective. Second, based on the ratings of three postgraduate students, we included only triplets for which all items were reportedly familiar to all three raters (i.e., understand the item at the first sight without effort). Third, we excluded triplets with items that might be more easily understood by people with special knowledge. For example, for items like "wave, distance, wire (the solution word was radio wave)," students with science majors might be more familiar with than those with arts majors. We also excluded triplets with items that might be more easily understood by students who grew up in village than in the city, e.g., items like "wheat seedling, vegetables, white flower (the solution word was leek)." Fourth, we excluded triplets that had more than one answer, e.g., for "baby, hot water, bathing cap," the answer could be bathroom, shower, or bathtub. Fifth, we excluded triplets with items that could be the answer of other triplets. Sixth, we ensured triplets with items that do not share any character with the corresponding solution words. For example, for triplets like "wood, flame, sharp-pointed," the solution word was match, but there was overlap for flame (火焰) and match (火柴) in Chinese.

Procedure

Participants received a questionnaire in which all 115 triplets were presented in a randomized order. For each triplet, three seemingly unrelated words were presented and participants were asked to figure out a solution word that was associated with each of the three words. No corrective feedback was given to participants. Then, they were instructed to rate the difficulty for each triplet in a 5-point scale, with 1 = very easy, 5 = very difficult. They were reminded to evenly distribute the ratings across the triplets. Finally, participants were asked to circle out words that they were not familiar with or words that they felt very difficult to understand. All of these tasks were self-paced.

Depending on their ratings, we excluded triplets with items that have multi-solutions or were with accuracy rate being higher than 0.94 or lower than 0.18. The accuracy rate and difficulty rating were highly correlated, $r = -.80$, $p < .05$, so we selected triplets for our experiments based on accuracy rate in this norming study. Because the RAT was conducted auditorily in Experiments 1 and 2, we ensured the selected triplets not to include homonyms by auditorily presenting all triplets to postgraduate students and asking them to comment on whether the words they heard was consistent with the words presented on the computer screen. For example, ill omen in "sky, feather, ill omen" was found to be misunderstood as bra in Chinese. After all screening procedures, 24 triplets were selected. The 24 triplets selected in the norming study were divided into two sets of 12 with similar mean accuracy rate [.58 vs. .57, $t(22) = .023$, $p = .982$] and difficulty rating [2.27 vs. 2.16, $t(22) = .491$, $p = .628$]. Each set (i.e., 12) was equally used across participants within each of the two bodily state conditions in Experiment 2, and one set of the 12 items was used in Experiment 1.

Experiment 1

Participants were randomly assigned to perform the AUT, RAT, and the auditory Stroop task in one of the three (sitting, standing, or roaming) conditions.

Methods

Participants

Based on Zhou et al. (2017, Experiment 1B), who compared the effect of standing and roaming on fluency, flexibility, and novelty scores in a consequences imagination task, the smallest Cohen's d was 1.088 ($M_{roaming}$ =3.18, $SD_{roaming}$ = .68; $M_{standing}$ = 2.51, $SD_{standing}$ = .52). Using G*power 3.1, we input the power as .95 and alpha level as .05 and found that for between-subject design, the required sample size was 23 participants for each of the three groups. Ninety-five college students from two universities in China participated in this experiment. Data of two participants were excluded for analyses due to not following the instruction (stopped roaming and kept static for longer than 80% of time in the experiment). Thus, data from 93 participants (31 for each of the 3 bodily state conditions) were analyzed (43 males and 50 females; mean age 20.10 years, ranged 17–26; mean height 167.64 cm, ranged 150–189; mean weight 59.82 kg, ranged 43–93 kg, all right-handed). In both experiments reported in this paper, all participants had normal or corrected-to-normal vision, normal audition, and did not have a physical disability or a history of neurological or psychiatric mental problems. All participants were informed in advance to wear comfortable flat shoes and to engage in no strenuous physical activity in 24 hours before the experiment. They were reminded half an hour before their experimental session to go to the lab, so that they did not walk in a hurry or run on their way to the lab. After finishing the experiment, each participant was paid 15/10 RMB for participation. No participant took part in more than one experiment. All experiments were approved by the Survey and Behavioral Research Ethics Committee of the relevant universities.

Physiological and mood measurements

Systolic blood pressure, diastolic blood pressure and heart rate were measured on the non-dominant arm with an automatic digital electronic wrist blood pressure monitor (Omron HEM-6131) before and after the experiment. Mood was rated on a 9 (Valence) × 9 (Arousal) Affect Grid, following Ma, Sellaro, Lippelt, and Hommel's (2016) procedure (see also Russell, Weiss, & Mendelsohn, 1989). The horizontal axis represents valence, ranging from unpleasantness (−4) to pleasantness (+4); the vertical axis represents arousal, ranging from sleepiness (−4) to arousal (+4). The affect grid was presented to participants before and after the experiment, they were asked to report the code in the grid that could best describe their current feeling on arousal and valence.

Materials and procedure

Alternate Uses Task. The task was used to assess divergent thinking (Christensen, Guilford, Merrifield, & Wilson, 1960; Guilford, Christensen, Merrifield, & Wilson, 1978. Participants were required to report as many unconventional uses as they could think of. Four object names (battery, newspaper, straw, tyre) were auditorily presented to participants. The task was run via E-Prime 1.0. The order of the trials was randomized for each participant. At the beginning of each trial, a voice prompt (680 ms) was presented, then an object name in Chinese was auditorily presented. Participants spoke out aloud as many novel uses as they could in 1 min (e.g., newspaper for making clothes). Then, the next object name was presented.

Remote Associates Task. We used this task to assess convergent thinking (Mednick, 1962). In each triplet, participants were presented three Chinese words. They thought of one solution word that had close and common relationship with each of the three words. e.g., bamboo for "panda-mat-flute." The mean normed accuracy rate was 0.57 (SD = .23) and mean normed difficulty rating was 2.16 (SD = .44) for the set of 12 items used in this experiment. The auditory stimuli were recorded by a female voice in Putonghua, speech sounds were delivered through headphones at the file format of 44,100 Hz, 16-bit, Stereo. Then noise reduction was done by Cool Editor Pro and edited into stimuli including each triplet of words. The task was run via E-Prime 1.0. The order of the trials was randomized for each participant. Each trial began with a voice prompt presented for 680 ms, then a three-word triplet was presented auditorily. The participants pressed a mouse button to indicate that they had solved the problem or until the 15s time limit elapsed. Following the button press, participants spoke out aloud the answer. Followed by 2 s intertrial interval, the next triplet was presented. If participants failed to press the button within the 15s time limit, the next triplet was presented.

Auditory Stroop task. There were congruent stimuli ("high" spoken in a high pitch or "low" spoken in a low pitch) and incongruent stimuli ("high" in low pitch or "low" in high pitch). Each of these four stimuli was presented 18 times, i.e., 72 trials in total. Each stimulus was trimmed to 300 ms using Cool Editor Pro. At the beginning of the task, participants were instructed to judge the pitch of the words they heard as quickly as possible, regardless of the meaning of the word. They were told that both speed and accuracy were equally important. In the practice trials, participants completed 16 trials, and the feedback for each trial was given. If they responded incorrectly for more than 4 trials, they were given another set of 16 practice trials. The task was run via E-Prime 1.0. The order of the trials presenting 4 stimuli was randomized for each participant. Each trial began with a voice prompt presented for 680 ms, immediately followed by an auditorily presented word (i.e., "high" or "low" in high or low pitch). Participants pressed a button once they recognized the pitch of the word within 1 s. Followed by 1 s intertrial interval, the next trial was presented. If participants did not press the button within 1 s, the next trial was presented. A pilot test, with 11 postgraduate students (2 males) from different majors as participants and the same procedure as stated above, was conducted to check whether the stimuli could yield a reliable Stroop effect. Results showed that there was a significant Stroop effect (1241 ms, SD = 230 for incongruent trials vs. 1144 ms, SD = 191 for congruent trials), $t(10) = 4.981$, $p < .01$, $d = 1.08$.

Bodily state manipulation. In the sitting condition, participants sat straightly on a chair, with their hands on the lap. In the standing condition, participants stood erectly, about 2.5 m away from a wall, with their arms hanging naturally. In the roaming condition, participants were asked to perform the tasks while roaming. They could walk freely in the room (the space for roaming was about 5.5 m × 6.5 m in one university, and 8.05 m × 4.16 m in the other university). There was no limit of speed or direction. Walking speed in the roaming condition (the number of steps a participant walked per minute) was recorded by the experimenter. It was based on the steps counted in the second minute since the first task began.

Overall procedure and design

The bodily state was manipulated between subjects. Participants were tested one by one. The consent form was obtained from each participant upon their arrival at the lab. Systolic and diastolic blood pressure, heart rate and mood were measured about 2 minutes after participants' arrival. Before measurement, we confirmed with the participants that they did not walk in a hurry or run on the way. Then participants did the practice trials for each of the three tasks before the actual experiment. Questions about the procedure were explained by experimenter to make sure that participants clearly understood the tasks. Participants were randomly assigned to one of the bodily state conditions: sitting, standing or roaming. In all conditions, participants wore a wireless headset (Rapoo S700 Bluetooth 4.1 Stereo NFC headset) and held a wireless mouse (HP blackfish wireless mouse) in the right hand to indicate their responses. Participants completed three tasks, AUT, RAT, and the auditory Stroop task. Verbal responses were recorded by two student helpers who knew nothing about the hypothesis and also recorded by microphone of the headset connected with a recording software in the computer. After participants completed all tasks, the experimenter checked with them for unclear responses (e.g., homophony or responses that could not be distinguished because of slurred words).

Post-experimental measurements

After the completion of cognitive tasks, systolic and diastolic blood pressure, heart rate, and mood were measured for the second time. The participants rated three items related to the "level of preference, sense of comfort, level of being accustomed to" for their bodily states, on a 7-point scale ranging from 1 (e.g., very uncomfortable) to 7 (very comfortable).

Results

Physiological and mood measurements. We analyzed the interaction effect between bodily state and session (before and after the tasks) on systolic and diastolic blood pressure and heart rate. No interaction effect was significant, all p >.05. For mood, arousal and valence were analyzed separately, but no significant interaction effect was found, all p >.05.

Alternate Uses Task. Following the data coding method of previous studies (e.g., Oppezzo & Schwartz, 2014; Zhou et al., 2017), fluency (number of uses for each object), flexibility (number of different categories of uses) and novelty score[1] were coded by trained research staff. Fluency, flexibility, and novelty scores were analyzed by one-way ANOVA with the bodily state condition as a factor. There was no significant effect of bodily state on fluency, $F(2,90) = .47$, $p > .05, \eta_p^2 = .01$ [2.84,SD = 1.48; 3.03, SD = 1.24, and 3.19,SD = 1.60, for the sitting, standing, and roaming conditions, respectively], flexibility, $F(2,90) = .48$, $p > .05, \eta_p^2 = .01$ [2.31, SD = 1.06; 2.56, SD = 1.00 and 2.55, SD = 1.25 for the sitting, standing, and roaming conditions, respectively], and novelty (one participant didn't give any response in the task, so data for novelty from this participant was missing), $F(2,89) = 1.12$, $p > .05, \eta_p^2 = .02$ [2.61, SD = .33; 2.69, SD = .28, and 2.57, SD = .34 for the sitting, standing, and roaming conditions, respectively]. And we analyzed the (Pearson) correlation between fluency, flexibility, and novelty in each condition, see Table 1.

To provide more information for the power of the null hypothesis, we used the software JASP (www.jasp-stats.org) (Wagenmakers et al., 2018a) to run Bayesian ANOVAs. One of the advantages of Bayesian analysis over the classical analysis is that the former can quantity the evidence that the data provided for null hypothesis versus alternative hypothesis (Wagenmakers et al., 2018b). The results indicated BF_{01} = 7.102 for fluency, 7.055 for flexibility, 4.220 for novelty (Accordingly, BF_{10} = 0.123, 0.124,0.227) in the AUT; all providing moderately strong evidence for the null hypothesis. The Bayes factor labeled as BF_{01} in JASP indicated the intensity of the evidence provide for null hypothesis (H_0) versus alternative hypothesis (H_1); for example, BF_{01} = 7.102 in the Bayesian ANOVA for fluency indicated the observed dataset is 7.102 times likely to be under H_0 as H_1. Accordingly, the Bayes factor BF_{10} indicated the possibility for the data to support alternative hypothesis(H_1) over the null hypothesis (H_0). The value of BF_{01} is the reciprocal of BF_{01} in mathematics. In the current study, most results provide strong evidence to support null hypothesis over alternative hypothesis. Thus, we used BF_{01} frequently as an indicator in the Bayesian analysis to make the results look straightforward. According to Wagenmakers et al. (2018a), BF_{01} >30 provides very strong evidence to support H_0; 10< BF_{01} < 30 provides strong evidence for H_0. 3< BF_{01} < 10 provides moderately strong evidence for H_0, and 1< BF_{01} < 3 provides weak evidence for H_0.

Remote Associates Task. Participants' mean accuracy and Reaction Times (RTs) for correct responses were

Table 1. Corelation between fluency, flexibility and novelty in the aternative uses task in each condition in experiment 1.

condition		fluency	flexibility	novelty
sitting	fluency			
	flexibility	.947**		
	novelty	.364*	.356*	
standing	fluency			
	flexibility	.919**		
	novelty	.086	.043	
roaming	fluency			
	flexibility	.963**		
	novelty	.378*	.394*	

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

analyzed by one-way ANOVA with the bodily state condition as a factor. RTs data of three participants (one in the standing and two in the roaming condition) were missing since they responded incorrectly in all trials. RTs data of another two participants were outliers beyond 3 *SD* from the overall participants' mean, so that their data were excluded from further analysis. There was no significant difference among three bodily state conditions in accuracy rate, $F(2,90) = .17$, $p > .05$, $\eta_p^2 = .004$, [28.76%, *SD* = 0.14; 29.30%, *SD* = 0.15; 30.91%, *SD* = 0.17 for sitting, standing, roaming condition, respectively], However, a significant difference was found for RTs, $F(2,85) = 3.27$, $p < .05$, $\eta_p^2 = .071$. The pairwise analysis indicated a significant difference between sitting (8725.38, *SD* = 1412.27) and roaming (7859.05, *SD* = 1355.41), $p < .05$, while no significant difference between RTs in the sitting and standing (8049.84, *SD* = 1342.31), or between standing and roaming conditions. Similarly, we used JASP to run Bayesian ANOVAs for RTs and accuracy in RAT. The results indicated $BF_{01} = 9.011$ for accuracy, and 1.311 (BF_{10} was 0.76) for RTs. This provided relatively strong evidence to support the null hypothesis for accuracy and weak evidence for RTs.

Since a previous study found roaming (vs. sitting) hindered performance in the convergent thinking task (Oppezzo & Schwartz, 2014), we ran Bayesian Paired Samples T-Test by JASP, and set the alternative hypothesis as Group 1(RTs in the sitting condition) <Group 2 (RTs in the roaming condition), which is consistent with the findings of that in Oppezzo and Schwartz's (2014) study. Results showed that $BF_{0-} = 11.51$, suggesting strong evidence against the hypothesis (RTs in the sitting condition < RTs in the roaming condition).

Auditory Stroop task. Accuracy rates of 8 participants were lower than 70%, which was beyond 3 *SD* from the overall participants' mean in their conditions, so their data were excluded from further analysis. RTs data were missing for another 2 participants because of problems with the mouse or computer. Mean RTs from 83 participants (28, 26, and 29 in the sitting, standing, and roaming conditions, respectively) and accuracy data from 85 participants (28, 27, and 30 in the sitting, standing, and roaming conditions, respectively) were submitted to the following analyses.

We submitted the RT and accuracy data to 2 (congruency: congruent or incongruent) x 3 (bodily state condition: sitting, standing, or roaming) mixed-factor ANOVAs with congruency being the within-subject variable. For accuracy rates, the main effect of congruency was significant, $F(1,82) = 3.995$, $p < .05$, $\eta_p^2 = .046$, [*M* = 94.44%, *SD* = .07; *M* = 92.88%, *SD* = .08 for congruent and incongruent condition, respectively]. However, neither the main effect of bodily state, $F(2,82) = .118$, $p > .05$, $\eta_p^2 = .003$; nor the interaction between congruency and bodily state were significant, $F(2,82) = .440$, $p > .05$, $\eta_p^2 = .011$. For RTs, the main effect of congruency was significant, $F(1,80) = 26.968$, $p < .001$, $\eta_p^2 = .252$. [*M* = 1014.95, *SD* = 180.92; *M* = 1045.55, *SD* = 192.43 for congruent and incongruent condition, respectively]. Again, neither the main effect of bodily state, $F(2,80) = 2.463$, $p > .05$, $\eta_p^2 = .058$; nor the interaction between congruency and bodily state were significant, $F(2,80) = .606$, $p > .05$, $\eta_p^2 = .015$. The results of Bayesian Repeated Measures ANOVA by JASP showed BF_{01} was 26.461, 3.956 for the interaction effect between congruency and bodily state on accuracy and RTs, which provided strong or moderately strong evidence for the observed dataset to be under the null hypothesis.

We analyzed the (Pearson) correlation between self-rated items (preference, comfort level, and accustomed level) and cognitive performance in three tasks, see Table 2. To statistically control for the potential confounding effect of preference, comfort level, accustomed level, we re-ran the above analyses with these three variables being controlled for. Yet similar to the above results, we found no significant main effect of bodily state in all three tasks in these ANCOVAs (all $p > .05$).

To test the possible influence of walking speed in the roaming condition, we analyzed the correlation between

Table 2. Correlation (Pearson) between variables in the post- experimental measurement and performance in three bodily state conditions in experiment 1.

bodily state		Fuency	Flexibility	Novelty	RATACC	RATRT	Stroopeffect
sitting	comfort	.206	.124	−.004	.394*	.001	−.406*
	accustomed	−.206	−.272	.03	.417*	−.188	−.174
	preference	−.082	−.111	.125	.289	−.173	−.401*
standing	comfort	.404*	.362*	−.286	−.035	−.035	.018
	accustomed	.219	.283	−.18	.264	.098	.263
	preference	.337	.381*	−.32	−.063	.096	.230
roaming	comfort	.177	.236	.189	−.203	.065	−.435*
	accustomed	.058	.077	.126	.127	−.165	−.338
	preference	.178	.185	.077	−.044	−.053	−.215

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Table 3. Correlation between stroop effect size and divergent thinking, convergent thinking in the three conditions in study 1.

	Fluency (AUT)	Flexibility (AUT)	Novelty score (AUT)	Accuracy rate (RAT)	Response time (RAT)
Sitting	−.029	−.049	−.096	−.374	−.065
Standing	.16	.07	−.142	.027	.011
Roaming	.138	.148	.124	.204	−.022

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

walking speed and measures in three tasks. The results indicated no significant correlation between walking speed and task performance in all three tasks (all $p > .05$). $r = -0.291, -0.213, -0.095$, for fluency, flexibility, and novelty score in the AUT, respectively. $r = -0.085$, 0.212, for accuracy rate, response time in the RAT, respectively. $r = -0.101$ for Stroop effect in the auditory Stroop task.

We also assessed the relationship between cognitive control and performance in the divergent thinking and convergent thinking tasks. Using correlation analysis, we found there was no significant correlation between Stroop effect and performance in divergent thinking and convergent thinking tasks (See Table 3). Regression analysis indicated there was no linear or non-linear regression (all $p > .05$) between Stroop effect size and all variables in AUT and RAT.

Discussion

In summary, none of the expected effects were observed. Neither did bodily state have any impact on the Stroop task, suggesting that there was no measurable depletion, nor was there any effect on divergent or convergent thinking. Before drawing further conclusions, we decided to see whether these null-findings can be replicated in a similar design, but with more sensitive within-participants measurements.

Experiment 2

To further examine the bodily state effect on divergent thinking, in this experiment we used a within-subject design with a focus on the comparison of roaming and standing. The design and procedure were similar to those in Experiment 1.

Methods

Participants. Similar to Experiment 1, we referred to the smallest Cohen's *d* of Zhou et al. (2017) to estimate the sample size. Using G*power 3.1, we input the power as .95 and alpha level as .05 (two-tail), and found that for a within-subject design, the required sample size was 9 participants. To reach a high statistical power, we decided to use a sample size of 40. Forty college students from two universities in China participated in this experiment (16 males, and 24 females; mean age 19.78 years, ranged 18–24; mean height 166.27 cm, ranged 153–178; mean weight 56.64 kg, ranged 42–78, all right-handed).

Design and Procedure. We used a within-subject design to compare the effect of roaming and standing. The design and procedure were the same as those of Experiment 1, except that only roaming and standing conditions were included to avoid fatigue. The order of two bodily state conditions were counterbalanced between participants.

Results

We adapted the same data coding procedure and analytic methods as in Experiment 1, unless specified otherwise.

Physiological and mood measurements. As in Experiment 1, we analyzed the interaction effect of bodily state and session on systolic and diastolic blood pressure and heart rate, as well as arousal and pleasure for mood. No significant interaction effect was found, all $p > .05$.

Alternate Uses Task. For novelty, the inter-rater reliability reached Cronbach's alpha of .763(FJPT) and .713 (NJUPT). Fluency, flexibility, and novelty scores were analyzed by one-way ANOVA with the bodily state condition as a factor. No significant difference between the two bodily state conditions was obtained for fluency, $t(39) = -.85$, $p > .05$,$d = .13$, [2.72 ($SD = 1.25$); 2.86 ($SD = 1.26$) for standing and roaming, respectively]; flexibility, $t(39) = -1.008$, $p > .05$,$d = .159$, [2.20 ($SD = .95$); 2.32 ($SD = 1.02$) for standing and roaming, respectively]; or novelty, $t(39) = -.234$, $p > .05$,$d = .04$, [2.61 ($SD = .29$); 2.63 ($SD = .62$) for standing and roaming, respectively]. Results of Bayesian Paired-sample T- test showed BF_{01} was 4.171, 3.654, 5.713 for fluency, flexibility, and novelty, respectively, which provide moderately strong evidence to support null hypothesis. Then we also analyzed the (Pearson) correlation between fluency, flexibility and novelty in each of the two conditions, see Table 4.

Table 4. Corelation between fluency, flexibility and novelty in the aternative uses task in each condition in experiment 2.

condition		fluency	flexibility	novelty
standing	fluency			
	flexibility	.934**		
	novelty	.276	.335*	
roaming	fluency			
	flexibility	.950**		
	novelty	−.057	−.022	

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Remote Associates Task. RTs data in the roaming condition for one participant was not recorded by E-primes due to mouse/computer problem, while there was no outlier beyond 3SD from the overall participants' mean in this study. Thus, data from 39 participants were valid for further analysis. For accuracy rate, pairwise t tests revealed that there was a significant difference between the standing condition, 33.31% (SD = .14) and roaming condition, 39.93% (SD = .19), $t_{(38)} = -2.043$, $p < .05$, $d = .33$. For RTs, the pairwise t test showed that there was no significant difference between the standing condition, 7706.99 ms (SD = 1476.91) and roaming condition, 7791.56 ms (SD = 1417.01), $t_{(38)} = -.359$, $p > .05$, $d = .06$. Results of Bayesian Paired-sample T-test showed BF_{01} was 0.896 (its inverse BF_{10} =1/ BF_{01} = 1.116), 5.454 for accuracy and RTs, respectively, when we set the alternative hypothesis as "Measure 1 ≠ Measure 2" in the Bayesian analysis by JASP. This provided moderately strong evidence to support null hypothesis for RTs. To check the hypothesis against that in the study of Oppezzo and Schwartz (2014) which found the accuracy rate in the roaming condition decreased comparing with sitting condition, here we set the alternative hypothesis as "Measure 1 (accuracy in the standing condition) > Measure 2(accuracy in the roaming condition)," results of Bayesian Paired Samples T-Test showed BF_{0+} = 16.27, which provided strong evidence against the previous findings (accuracy in the standing condition > accuracy in the roaming condition).

Auditory Stroop task. We submitted the RTs and accuracy data to 2 (congruency: congruent or incongruent) x 2 (bodily state condition: standing or roaming) repeated-measure ANOVAs. Data of accuracy for three participants were outliers beyond 3 SD from the overall participants' mean in their conditions, so their data were excluded from further analysis. Data of responses for all items from 1 participant was missing because of a mouse problem. Thus, data from 38 participants were valid for further analysis.

For accuracy, the main effect of congruency was close to, but did not reach significance, $F(1,35) = 4.061$, $p = .052$, $\eta_p^2 = .104$, [95.45%, SD = 0.07; 94.37%, SD = 0.08 for congruent and incongruent conditions, respectively]. The main effect of bodily state was not significant, $F(1,35) = .785$, $p > .05$, $\eta_p^2 = .022$, [94.37%, SD = 0.07; 94.68%, SD = 0.08 for standing and roaming, respectively], nor the interaction between congruency and bodily state, $F(1,35) = .409$, $p > .05$, $\eta_p^2 = .012$. For RTs, the main effect of congruency was significant, $F(1,35) = 17.403$, $p < .001$, $\eta_p^2 = .332$, [1026.43 ms, SD = 218.87; 1055.73 ms, SD = 219.80 for congruent and incongruent conditions, respectively], as was the main effect of bodily state, $F(1,35) = 4.395$, $p < .05$, $\eta_p^2 = .112$, [1023.81 ms, SD = 223.46; 1058.34 ms, SD = 214.74 for standing and roaming, respectively], but there was no interaction between congruency and bodily states for response time, $F(1,35) = 3.342$, $p > .05$, $\eta_p^2 = .087$. More importantly, results of Bayesian Repeated Measure ANOVA provided evidence to support null hypothesis for the observed dataset on the interaction effect between congruency and bodily state on accuracy (Bayes factor was 6.254 for the exclusion of interaction effect) and RTs (weak evidence for all models, all BF_{10} ≤1.0) (see Appendix 1 for the tables generated by JASP).

Similar to Experiment 1, we analyzed the correlation (Pearson) between self-rated items (preference, comfort level, and accustomed level) and cognitive performance in three tasks, see Table 5 and re-ran the above analyses controlling for the potential confounding effect of preference, comfort level, and accustomed level. Results showed that none of the bodily state effects in AUT, RAT and auditory Stroop task approached significance (all $p > .05$).

We conducted correlation analyses to test the relationship between walking speed and performance in the roaming condition in various tasks to check the possible influence of walking speed. The results indicated only a significant correlation between walking speed and RT ($r = -.446$ $p < .01$) in the roaming condition in RAT, no significant correlation between walking speed and task performance in other variables in three tasks (r = .028, .057, −.212 for fluency, flexibility and novelty in AUT, respectively; r =−.118 for accuracy rate in the RAT, r = −.007 for Stroop effect in the auditory Stroop task).

We also consider the relationship between cognitive control and performance in the divergent thinking and convergent thinking tasks. Using correlation analysis, we found significant correlation between Stroop effect and fluency (r =0.415, $p < .05$) and flexibility (r =0.402, $p < .05$) in AUT, there was no significant correlation between Stroop effect and other creative performance in both AUT and RAT (see Table 6). Regression analysis indicated Stroop effect size could positively predict fluency and flexibility score (See Table 7), no other liner or non-liner regression between Stroop effect size and variables in AUT and RAT.

Table 5. Correlation (Pearson) between variables in the post- experimental measurement and performance in two bodily state conditions in experiment 2.

bodily state		fluency	flexibility	novelty	RATACC	RATRT	stroopeffect
standing	preference	.067	.075	.069	−.024	.039	−.050
	comfort	.062	.043	.130	.021	−.015	−.018
	accustomed	.124	.131	−.182	.026	−.083	−.108
roaming	preference	.229	.199	−.212	.171	.358*	.119
	comfort	.048	−.015	−.027	.062	.264	−.040
	accustomed	.190	.117	−.318*	.139	.235	.074

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Table 6. Correlation between stroop effect size and divergent thinking, convergent thinking in the two conditions.

	Fluency (AUT)	Flexibility (AUT)	Novelty score (AUT)	Accuracy rate (RAT)	Response time (RAT)
Standing	.415*	.402*	.322	−.001	−.045
Roaming	.044	.022	.035	.128	.108

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Table 7. Regression analysis of stroop effect size on fluency and flexibility in experiment 2.

	Predictors	R	R^2	F	B	β	t	p
Model		0.415	0.148	7.093*				
Fluency	Stroop effect				0.01	0.415	2.663	<.05
Model		0.402	0.137	6.552*				
Flexibility	Stroop effect				0.008	0.402	2.56	<.05

Note: ** p < .01. Difficulty refers to difficulty in chocolate consumption. R^2 shows the adjusted R^2

Interim discussion

In summary, no significant bodily state effect was found on divergent thinking and convergent thinking task in the present experiments, contrary to the previous finding that walking could promote creative ideas (Kuo & Yeh, 2016; Leung et al., 2012; Oppezzo & Schwartz, 2014; Zhou et al., 2017). To explore the possible explanations to account for the discrepancy, we conducted combined analysis based on three groups (a) the data of the divergent thinking task (Consequences Imagination Task) in Zhou et al. (Experiment 1B) and (b and c) Experiments 1 and 2′s data in the AUT in the current study. We focused on four possibilities that might result in this difference. As the procedure for rating of novelty scores was slightly different between Zhou et al. (2017) and current study, we used fluency and flexibility score as the indicators, which were reported as the most consistent and reliable indicators (e.g., Akbari Chermahini & Hommel, 2012; Colzato, Szapora, Pannekoek, & Hommel, 2013).

Possible influence of walking speed in the roaming condition

Using ANOVA, we compared the difference of walking speed in the roaming condition between the three groups. There was a significant difference, $F(2,129) = 4.107$, $p < .05$, $\eta_p^2 = .060$: The walking speed in the current Experiment 1 (M = 55.90 steps/min, SD = 13.63) was significantly slower than that in Zhou et al. (2017) (M = 64.78 steps/min, SD = 12.82), $p < .01$, in, $p = .057$. There was no significant difference between walking speed in Zhou et al. (2017) and that in Experiment 2 (M = 62.25 steps/min, SD = 15.39), $p > .05$, or between the current Experiment 1 and Experiment 2. To further examine the effect of walking speed, we grouped participants in the roaming condition in each experiment into high walking speed group and low walking speed group and compared the difference of walking speed group on cognitive performance. See Table 8 for the mean and standard deviation of walking speed, and the fluency and flexibility scores in each group for each experiment.

In summary, results of the combined analysis show that walking speed in the divergent thinking task in Zhou et al. (2017) was higher than that in the current Experiment 1, but equivalent to Experiment 2. In Zhou et al. (2017), participants with high walking speed got higher fluency and flexibility scores in the divergent thinking task than those with low walking speed. However, no such difference on creativity performance occurred in the current Experiments 1 and 2. Furthermore, for the current two experiments, using data of participants with fast walking speed in the roaming condition to compare with those in the sitting and standing conditions, we still did not obtain any significant

Table 8. The comparison of low/high walking speed on creativity performance in each study.

	group	N	Mean(SD) (steps/min)	fluency	flexibility	novelty
Zhou et al. (2017)	low walking speed	31	55.18 (5.38)	3.37 (.75)	3.00(.67)	3.19 (0.18)
	high walking speed	32	74.08 (10.92)	3.82 (.63)	3.35(.65)	3.26 (0.20)
	t test between two groups			$t(61) = -2.62$, $p < .05$, $d = 0.65$	$t(61) = -2.08$, $p < .05$, $d = 0.53$	$t(61) = -1.39$, $p > .05$, $d = 0.37$
Experiment1	low walking speed	15	46.13 (10.15)	3.32 (1.09)	2.58 (.90)	2.52 (0.28)
	high walking speed	14	66.36 (7.84)	3.00 (2.05)	2.45 (1.57)	2.63 (0.41)
	t test between two groups			$t(27) = 0.52$, $p > .05$, $d = 0.19$,	$t(27) = 0.29$, $p > .05$, $d = 0.10$	$t(27) = - 0.83$, $p > .05$, $d = 0.31$
Experiment2	low walking speed	20	50.85 (10.19)	2.86(1.31)	2.31 (.90)	2.76(0.84)
	high walking speed	20	73.65 (10.43)	2.85 (1.25)	2.34 (1.15)	2.50(0.22)
	t test between two groups			$t(38) = 0.03$, $p > .05$, $d = 0.01$	$t(38) = -0.077$, $p > .05$, $d = 0.03$	$t(38) = 1.391$, $p > .05$, $d = 0.42$

Table 9. The interaction effect between difficulty and bodily state in remote association task in each study.

			accuracy rate			*response time*		
			sitting	standing	roaming	sitting	standing	roaming
	difficulty*bodily state		$F(2,88) = 0.355$, $p > .05$, $\eta p2 = .008$;			$F(2,55) = 0.249$, $p > .05$, $\eta_p^2 = .009$;		
Experiment1	low difficulty	22	20.16% (.12)	19.62% (.11)	22.70% (.12)	8506.12 (2117.22)	7901.48 (1173.10)	7956.25(1684.53)
	high difficulty	21	8.60% (.09)	9.68% (.08)	9.77% (.08)	8679.06 (2001.56)	8355.59 (2219.20)	8633.80(1833.72)
	difficulty*bodily state		$F(1,38) = 0.474$, $p > .05$, $\eta_p^2 = .012$			$F(1,21) = 0.158$, $p > .05$, $\eta_p^2 = .007$.		
Experiment2	low difficulty	10		22.15% (.11)	24.31% (.13)		7740.58 (1741.85)	7678.78 (1424.97)
	high difficulty	10		10.62% (.09)	15.21% (.10)		8147.32 (1456.37)	7832.70 (1643.29)

bodily state effect on the performance in the divergent thinking task ($p > .05$). All this suggests that walking speed differences between participants in the two studies cannot systematically account for the discrepancy of the findings.

Possible influence of the baseline creativity of different samples

To check whether there were some differences in the baseline creativity for the samples in the current study and in Zhou et al. (2017, Experiment 2A), we ran combined analyses on the data of Experiment 1′s sitting condition in the AUT from Zhou et al. (2017) and in the current study. We took that as a baseline condition since people usually complete tasks in the sitting bodily state. Results revealed that there was no significant difference between scores in Zhou et al. (2017) and the current Experiment 1 in the baseline fluency score [$M = 3.20$, $SD = 1.16$ vs. $M = 2.84$, $SD = 1.48$, $t(89) = 1.262$, $p > .05$, $d = 0.27$] and the baseline flexibility score, $M = 2.67$, $SD = .85$ vs. $M = 2.31$, $SD = 1.06$, $t(89) = 1.732$, $p > .05$, $d = 0.37$. Thus, no significant difference on creative scores were found between two studies, suggesting that baseline creativity cannot not explain the discrepancy of findings in these studies.

Potential influence of task duration

The task duration across studies was different. Zhou et al.'s (2017, Experiment 1B) divergent thinking task lasted for 10 minutes (totally 10 trials, 1 minute for each trial), while we used 4 trials in the current divergent thinking task that lasted for 4 minutes. To examine whether the task duration had an influence on creativity performance, we re-analyzed the performance in Zhou et al.'s standing and roaming condition based on their first four trials in the divergent thinking task in Experiment 1B. We found there was still significant difference between standing and roaming condition on fluency, $t(62) = 10.05$, $p < .001$, $d = -1.20$, [3.03, $SD = .63$ vs. 3.91, $SD = .82$ for standing and roaming, respectively], flexibility, $t(62) = 9.96$, $p < .001$, $d = 1.24$, [3.47 ($SD = .76$) vs. 2.65 ($SD = .55$)]. Thus, task duration could not account for the discrepancy between the findings in Zhou et al. (2017) and in the current study.

Potential influence of difficulty on the bodily state effect on convergent thinking

For Experiment 1, we divided 12 items into high and low difficulty groups depending on the accuracy of the normed RAT, and then analyzed the interaction effect between difficulty and bodily state on accuracy rate and RTs for Experiment 1 and 2. See Table 9 for the results of interaction effect and mean and standard deviation in each group.

Results indicated there was no significant interaction effect was found on accuracy or RTs in both studies.

General discussion

The goal of the present study was to extend previous studies (Kuo & Yeh, 2016; Leung et al., 2012; Oppezzo & Schwartz, 2014; Zhou et al., 2017) and test whether the findings on the impact of bodily state on divergent thinking could be replicated and generalized to other creativity tasks, like convergent thinking. Also, we aimed to test whether depletion of cognitive control really play a role in this impact.

The effect of bodily state on divergent thinking

The significant promoting effect of walking on divergent thinking obtained in previous studies (Kuo & Yeh, 2016; Leung et al., 2012; Oppezzo & Schwartz, 2014; Zhou et al., 2017) could not be replicated in the current study. Previous studies showed that walking could help to promote divergent thinking (Kuo & Yeh, 2016; Leung et al., 2012; Oppezzo & Schwartz, 2014; Zhou et al., 2017), while in the current study we obtained no significant effect of bodily state on divergent thinking. To find out why this discrepancy occurred, we discussed three potential factors and conducted combined analyses based on the data of Zhou et al.'s (Experiment 1B) divergent thinking task (i.e. consequences imagination task) and the current two experiments (AUT). These factors are walking speed in the roaming condition, baseline creativity of different samples, and task duration.

The correlation analysis relating walking speed to task performance in each study, as well as the results of the combined analysis, do not suggest that walking speed can explain the discrepancies. Only in Zhou et al. (2017), it was found participants in the high walking speed group showed higher fluency and flexibility scores in the divergent thinking task than those in the low walking speed group. However, no such difference on creativity performance occurred in the current Experiments 1 and 2. We are not aware of any research that has directly compared the influence of slow and fast walking on creativity. Walking involved in previous studies was of different speed: acute walking (with fast speed, participants were told to walk as late for class) or walking at normal speed. Intense walking (participants' self-selected pace as when late for class) had no significant effect on divergent thinking and convergent thinking (Frith & Loprinzi, 2018; Patterson, Frith, & Loprinzi, 2018), while walking at norm speed (Kuo & Yeh, 2016; Leung et al., 2012; Oppezzo & Schwartz, 2014; Zhou et al., 2017) was found to promote divergent thinking. This pattern was contrary to what we found in the combined analysis (fast walking promotes divergent thinking), so future studies should identify the moderating variables that account for the discrepancies of these findings.

Results also showed there was no significant difference on baseline creativity of participants in the previous study of Zhou et al. (2017) and the current study. It does not seem farfetched from anecdotal stories that some highly creative people like thinking in a stand-up posture (Hotchner, 2005) or while roaming (Nietzsche, 1897). And yet, it is still far from clear why the bodily states might exert a stronger effect on highly creativity people. So far, no research has paid attention to possible interactions between baseline creativity and bodily state effect. Future studies might explore this possibility more systematically. We also tried to figure out whether the duration of the tasks might play a role, but we found no evidence that it might. In conclusion, there is no obvious account for our failure of finding a bodily state effect on divergent thinking.

The effect of bodily state on convergent thinking

In the present study, results from the RAT in both Experiment 1 and 2 fail to replicate the results of Oppezzo and Schwartz (2014). These authors found walking to significantly decrease the accuracy rate in the RAT, which is not consistent with our observations. We tried to figure out whether difficulty of items in the RAT had a moderating effect, but found no significant interaction between bodily state and difficulty of items. Individual differences may play a role (see Colzato et al., 2013), but more systematic research will be necessary to evaluate this possibility.

The effect of bodily state on the stroop task

In the present study, no significant interaction between congruency and bodily state was found, and the Bayesian analysis provided quite strong evidence to support the null hypothesis. This is inconsistent with Rosenbaum et al. (2017)'s finding that standing, relative to sitting, can reduce the Stroop effect.

The relationship between cognitive control and creativity

An important aim of our study was to clarify whether the depletion of cognitive control resources might play a role in bodily state effects. Inconsistent with previous research, which found that control was positively related to divergent thinking performance (Nusbaum & Silvia, 2011), we only observed a significant relationship between cognitive control and divergent thinking in the experiment 2: the Stroop effect could positively predict fluency and flexibility score in AUT. However, in the current study, the larger the Stroop effect size (the smaller the cognitive control size), the worse the divergent thinking performance, which is in the opposite pattern of that in Nusbaum and Silvia's study. This might reflect differences in methodology. Nusbaum and Silvia used switching (the number of unique response categories) and clustering (the number of responses within that category) of responses in the AUT as indicators of cognitive control and used a "creativity score" as the indicator of divergent performance. However, "switching" is similar to our flexibility score, "clustering" size is equal to fluency/flexibility in the current study, and "creativity" similar to "novelty," so that it still remains unclear why we failed to replicate previous findings.

Conclusion

We did not find any stable effect of bodily state on divergent or convergent thinking, and there was no evidence for bodily state effects on Stroop performance. Taken altogether, our findings question the validity, or at least the generality of bodily state effects. It is possible that an even more extreme manipulation of bodily state would have been more successful in generating such effects and showing more direct evidence of resource depletion and the Stroop task. However, our observations suggest that, if bodily state effects on creativity exist at all, they seem to rely on context conditions that are not yet sufficiently well understood. Hence, if bodily state effects are real, they are subtle and cannot be expected to easily replicate and generalize.

Notes

1. Data for the current study was collected in two universities separately with the same procedure, and novelty was rated on a 5-point scale (1 = not novel at all; 5 = very novel) by three or two research staff with the same training on novelty score rating. The inter-rater reliability reached a Cronbach's alpha of .63 or .706.

Acknowledgments

We would like to thank Professor Chi-Shing Tse for his great contribution on the experimental design and revision of the earlier version of manuscript; Xiaomei Chen, Xianda Huang and XinYi He for their help on data collection; Yuxi Zhu for his help on novelty rating; Weijing Wei for her assistance on audio stimuli.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

The research was supported by the Science Foundation of Nanjing University of Posts and Telecommunications (NJUPTSF, NYY221022; Science Foundation of Nanjing University of Posts and Telecommunications).

Author contributions

YZ and BH contributed to the study design. YZ performed the data collection and analyses. YZ and BH wrote the paper. Both authors have approved the final version of the manuscript for submission.

Data availability statement

The data that support the findings of this study are available in Open Science Framework at: https://osf.io/qj46e/ or by DOI: 10.17605/OSF.IO/QJ46E

References

Akbari Chermahini, S., & Hommel, B. (2012). Creative mood swings: Divergent and convergent thinking affect mood in opposite ways. *Psychological Research*, *76*(5), 634–640. doi:10.1007/s00426-011-0358-z

Baumeister, R. F. (1998). The self. In D. Gilbert, S. T. Fiske, & G. Lindzey (Eds.), *Handbook of social psychology* (4th ed., pp. 680–740). New York: McGraw-Hill.

Berlyne, D. D. (1957). Conflict and choice time. British Journal of Psychology. 48, 106–118. doi: 10.1111/j.2044-8295.1957.tb00606.x

Beurskens, R., & Bock, O. (2013). Does the walking task matter? Influence of different walking conditions on dual-task performances in young and older persons. *Human Movement Science*, *32*(6), 1456–1466. doi:10.1016/j.humov.2013.07.013

Cann, M. T., (1990), *Age and speed of behavior: Effects of gender, posture-induced arousal, and task loading* (Master's thesis). Los Angeles: University of Southern California.

Chen,Q.,Luo, J., Jiang,J.,Wei, D.,& Zhang, Q. (2012). Effects of Unconscious Processing on Creativity Problems Solving. *Psychological Development and Education*,6,569–575. doi: 10.16187/j.cnki.issn1001-4918.2012.06.015.

Christensen, P. R., Guilford, J. P., Merrifield, P. R., & Wilson, R. C. (1960). *Alternate Uses (Form A)*. Beverly Hills, CA: Sheridan Psychological Services.

Colzato, L. S., Szapora, A., Pannekoek, J. N., & Hommel, B. (2013). The impact of physical exercise on convergent and divergent thinking. *Frontiers in Human Neuroscience*, *7* (824). doi:10.3389/fnhum.2013.00824

Courtine, G., & Schieppati, M. (2003). Human walking along a curved path. II. Gait features and EMG patterns. *European Journal of Neuroscience*, *18*(1), 191–205. doi:10.1046/j.1460-9568.2003.02737.x

Finke, R. A., Ward, T. B., & Smith, S. M. (1992). *Creative cognition: Theory. research, and applications*. Cambridge, MA: MIT Press.

Frith, E., & Loprinzi, P. D. (2018). Experimental effects of acute exercise and music listening on cognitive creativity. *Physiology & Behavior*, *191*, 21–28. doi:10.1016/j.physbeh.2018.03.034

Glazer, E. (2009). Rephrasing the madness and creativity debate: What is the nature of the creativity construct? *Personality & Individual Differences*, *46*(8), 755–764. doi:10.1016/j.paid.2009.01.021

Gruszka, A., & Necka, E. (2002). Priming and acceptance of close and remote associations by creative and less creative people. *Creativity Research Journal*, *14*(2), 193–205. doi:10.1207/S15326934CRJ1402_6

Guilford, J. P. (1967). *The nature of human intelligence*. New York,NY: McGraw-Hill.

Guilford, J. P., Christensen, P. R., Merrifield, P. R., & Wilson, R. C. (1978). *Alternate Uses: Manual of instructions and interpretations*. Orange, CA: Sheridan Psychological Services.

Hess, R. J., Brach, J. S., Piva, S. R., & VanSwearingen, J. M. (2010). Walking skill can be assessed in older adults: Validity of the figure-of-8 walk test. *Physical Therapy*, *90* (1), 89–99. doi:10.2522/ptj.20080121

Hommel, B., & Colzato, L. S. (2017). The social transmission of metacontrol policies: Mechanisms underlying the interpersonal transfer of persistence and flexibility. *Neuroscience and Biobehavioral Reviews*, *81*, 43–58. doi:10.1016/j.neubiorev.2017.01.009

Hotchner, A. E. (2005). *Papa Hemingway: A personal memoir*. Boston: Da Capo Press.

Howard-Jones, P. A., & Murray, S. (2003). Ideational productivity, focus of attention, and context. *Creativity Research Journal*, *15*, 153–166. doi:10.1207/S15326934CRJ152&3_07

IJzerman, H., & Koole, S. L. (2011). From perceptual rags to metaphoric riches— Bodily, social, and cultural constraints on sociocognitive metaphors: Comment on Landau, Meier, and Keefer (2010). *Psychological Bulletin*, *137*(2), 355–361. doi:10.1037/a0022373

Kerr, B., Condon, S. M., & McDonald, L. A. (1985). Cognitive spatial processing and the regulation of posture. *Journal of Experimental Psychology: Human Perception and Performance*, *11*(5), 617. doi:10.1037/0096-1523.11.5.617

Kuo, C. Y., & Yeh, Y. Y. (2016). Sensorimotor-Conceptual Integration in Free Walking Enhances Divergent Thinking for Young and Older Adults. *Frontiers in Psychology*, *7*, 1580. doi:10.3389/fpsyg.2016.01580

Lacour, M., Bernard-Demanze, L., & Dumitrescu, M. (2008). Posture control, aging, and attention resources: Models and posture-analysis methods. *Neurophysiologie Clinique/Clinical Neurophysiology*, *38*(6), 411–421. doi:10.1016/j.neucli.2008.09.005

Lacour, M., & Borel, L. (1993). Vestibular control of posture and gait. *Archives Italiennes De Biologie*, *131*(2), 81–104.

Lajoie, Y., Teasdale, N., Bard, C., & Fleury, M. (1993). Attentional demands for static and dynamic equilibrium. *Experimental Brain Research*, *97*(1), 139–144. doi:10.1007/BF00228824

Lajoie, Y., Teasdale, N., Bard, C., & Fleury, M. (1996). Upright standing and gait: Are there changes in attentional requirements related to normal aging? *Experimental Aging Research*, *22*(2), 185–198. doi:10.1080/03610739608254006

Landau, M. J., Meier, B. P., & Keefer, L. A. (2010). A metaphor-enriched social cognition. *Psychological Bulletin*, *136*(6), 1045–1067. doi:10.1037/a0020970

Leung, A. K. Y., Kim, S., Polman, E., Ong, L. S., Qiu, L., Goncalo, J. A., & Sanchez-Burks, J. (2012). Embodied metaphors and creative “acts.” *Psychological Science*, *23*(5), 502–509. doi:10.1177/0956797611429801

Lindenberger, U., Marsiske, M., & Baltes, P. B. (2000). Memorizing while walking: Increase in dual-task costs from young adulthood to old age. *Psychology and Aging*, *15*(3), 417. doi:10.1037/0882-7974.15.3.417

Lipnicki, D. M., & Byrne, D. G. (2005). Thinking on your back: Solving anagrams faster when supine than when standing. *Cognitive Brain Research*, *24*(3), 719–722. doi:10.1016/j.cogbrainres.2005.03.003

Lowry, K. A., Brach, J. S., Nebes, R. D., Studenski, S. A., & VanSwearingen, J. M. (2012). Contributions of cognitive function to straight-and curved-path walking in older adults. *Archives of Physical Medicine and Rehabilitation*, *93*(5), 802–807. doi:10.1016/j.apmr.2011.12.007

Martindale, C. (1995). Creativity and connectionism. In S. M. Smith, T. B. Ward, & R. A. Finke (Eds.), *The creative cognition approach* (pp. 255–259). Cambridge, MA: MIT Press.

Martindale, C. (1999). *7 biological bases of creativity* (pp. 137–152). Cambridge: Cambridge University Press.

Ma, K., Sellaro, R., Lippelt, D. P., & Hommel, B. (2016). Mood migration: How enfacing a smile makes you happier. *Cognition*, *151*, 52–62. doi:10.1016/j.cognition.2016.02.018

Mednick, S. (1962). The associative basis of the creative process. *Psychological Review*, 69, 220–232. https://doi.org/10.1037/h0048850

Muraven, M., & Baumeister, R. F. (2000). Self-regulation and depletion of limited resources: Does self-control resemble a muscle? *Psychological Bulletin*, *126*(2), 247–259. doi:10.1037/0033-2909.126.2.247

Muraven, M., Tice, D. M., & Baumeister, R. F. (1998). Self-control as a limited resource: Regulatory depletion patterns. *Journal of Personality and Social Psychology*, *74*(3), 774. doi:10.1037/0022-3514.74.3.774

Nietzsche, F. (1897). *Twilight of the Idols*. New York: Oxford University Press.p61.

Nusbaum, E. C., & Silvia, P. J. (2011). Are intelligence and creativity really so different?: Fluid intelligence, executive processes, and strategy use in divergent thinking. *Intelligence*, *39*(1), 36–45. doi:10.1016/j.intell.2010.11.002

Oppezzo, M., & Schwartz, D. L. (2014). Give your ideas some legs: The positive effect of walking on creative thinking. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *40*(4), 1142. doi:10.1037/a0036577

Patterson, R., Frith, E., & Loprinzi, P. D. (2018). The experimental effects of acute walking on cognitive creativity performance. *Journal of Behavioral Health*, *7*(3), 113–11910. doi:10.5455/jbh.20180415053930

Radel, R., Davranche, K., Fournier, M., & Dietrich, A. (2015). The role of (dis) inhibition in creativity: Decreased inhibition improves idea generation. *Cognition*, *134*, 110–120. doi:10.1016/j.cognition.2014.09.001

Rosenbaum, D., Mama, Y., & Algom, D. (2017). Stand by your stroop: Standing up enhances selective attention and cognitive control. *Psychological Science*, *28*(12), 1864–1867. doi:10.1177/0956797617721270

Russell, J. A., Weiss, A., & Mendelsohn, G. A. (1989). Affect grid: A single-item scale of pleasure and arousal. *Journal of Personality and Social Psychology*, *57*(3), 493. doi:10.1037/0022-3514.57.3.493

Slepian, M. L., & Ambady, N. (2012). Fluid movement and creativity. *Journal of Experimental Psychology: General*, *141* (4), 625. doi:10.1037/a0027395

Smith, S. M. (1995). Fixation, incubation and insight in memory and creative thinking. In S. M. Smith, T. B. Ward, & R. A. Finke (Eds.), *The Creative Cognition Approach* (pp. 135–156). Cambridge, MA: MIT Press.

Srygley, J. M., Mirelman, A., Herman, T., Giladi, N., & Hausdorff, J. M. (2009). When does walking alter thinking? Age and task associated findings. *Brain Research*, *1253*, 92–99. doi:10.1016/j.brainres.2008.11.067

Vercruyssen, M., & Simonton, K. (1988). Effects of posture on mental performance: We think faster on our feet than on our seat. *Hard facts about soft machines—the ergonomics of seating*. Bristol, PA: Taylor and Francis, 119–131.

Wagenmakers, E. J., Love, J., Marsman, M., Jamil, T., Ly, A., Verhagen, J., . . . Morey, R. D. (2018a). Bayesian inference for psychology. Part II: Example applications with JASP. *Psychonomic Bulletin & Review*, *25*(1), 58–76. doi:10.3758/s13423-017-1323-7

Wagenmakers, E. J., Marsman, M., Jamil, T., Ly, A., Verhagen, J., Love, J., . . . Morey, R. D. (2018b). Bayesian inference for psychology. Part I: Theoretical advantages and practical ramifications. *Psychonomic Bulletin & Review*, *25*(1), 35–57. doi:10.3758/s13423-017-1343-3

Woods, A. M. (1981). *Age differences in the effect of bodily state and postural changes on information processing speed*. (Doctoral Dissertation). The University of Southern California: Los Angeles. 90089–90191.

Woollacott, M., & Shumway-Cook, A. (2002). Attention and the control of posture and gait: A review of an emerging area of research. *Gait & Posture*, *16*(1), 1–14. doi:10.1016/S0966-6362(01

Zabelina, D. L., & Robinson, M. D. (2010). Creativity as flexible cognitive control. *Psychology of Aesthetics, Creativity, and the Arts*, *4*(3), 136. doi:10.1037/a0017379

Zhou, Y., Zhang, Y., Hommel, B., & Zhang, H. (2017). The impact of bodily states on divergent thinking: Evidence for a control-depletion account. *Frontiers in Psychology*, *8*(1546). doi:10.3389/fpsyg.2017.01546

Appendix

Bayesian Repeated Measures ANOVA for Accuracy in Auditory Stroop Task.

Model Comparison

Models	P(M)	P(M|data)	BF_M	BF_{01}	error %
Null model (incl. subject and random slopes)	0.2	0.34	2.062	1	
congruency	0.2	0.293	1.657	1.161	11.635
bodilystate	0.2	0.192	0.95	1.773	11.2
congruency + bodilystate	0.2	0.137	0.633	2.491	11.575
congruency + bodilystate + congruency ✻ bodilystate	0.2	0.038	0.16	8.85	11.365

Note. All models include subject, and random slopes for all repeated measures factors

Analysis of Effects

Effects	P(incl)	P(excl)	P(incl|data)	P(excl|data)	BF_{excl}
congruency	0.6	0.4	0.468	0.532	1.706
bodilystate	0.6	0.4	0.367	0.633	2.588
congruency ✻ bodilystate	0.2	0.8	0.038	0.962	6.254

Bayesian repeated measures ANOVA for RTs in Auditory Stroop Task.

Model comparison

Models	P(M)	P(M|data)	BF_M	BF_{10}	error %
bodilystate + congruency	0.2	0.444	3.2	1	
bodilystate + congruency + bodilystate ✻ congruency	0.2	0.327	1.94	0.74	11.118
congruency	0.2	0.225	1.16	0.51	9.667
bodilystate	0.2	0.003	0.01	0.01	11.628
Null model (incl. subject and random slopes)	0.2	0.002	0.01	0	9.405

Note. All models include subject, and random slopes for all repeated measures factors.

Analysis of Effects

Effects	P(incl)	P(excl)	P(incl|data)	P(excl|data)	BF_{incl}
bodilystate	0.6	0.4	0.774	0.226	2.279
congruency	0.6	0.4	0.996	0.004	157.433
bodilystate ✻ congruency	0.2	0.8	0.327	0.673	1.941