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How we walk affects what we remember: Gait modifications through biofeedback change negative affective memory bias

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ABSTRACT

Background and objects: Several studies have shown that physical exercise such as walking has effects on depression. These studies have focused on increasing intensity and amount of physical activity. In the present study, we investigated whether not only the intensity but also the style of physical activity affects depression related processes.
Method: Using an unobtrusive biofeedback technique, we manipulated participants (39 undergraduates) to change their walking patterns to either reflect the characteristics of depressed patients or a particularly happy walking style. The intensity of walking (i.e. walking speed) was held constant across condition. During walking, participants first encoded and later recalled a series of emotionally loaded terms.
Results: The difference between recalled positive and recalled negative words was much lower in participants who adopted a depressed walking style as compared to participants who walked as if they were happy.
Limitations: The effects of gait manipulation were investigated in a non-clinical group of undergraduates.
Conclusions: The observed change in memory bias supports the idea that beyond the intensity of walking the style of walking has effects on the vulnerability to depression.
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1. Introduction

A number of studies have shown that physical exercise has effects on mood and can be therapeutic for patients suffering from Major Depressive Disorders (MDD). In a meta-analysis by Reed and Ones (2006) including 158 studies it was shown that engaging in acute exercise (e.g. walking) increases positive affect. In addition, Mata et al. (2012) found that natural variations in physical activity had effects on mood in depressed individuals. In this 1-week experience sampling study depressed individuals expressed higher levels of positive affect when they were physically active than during sedentary periods. Moreover, studies investigating physical exercise as a treatment approach have documented that engaging in prescribed exercise significantly reduces levels of depressive symptoms in clinical samples (Conney et al., 2013). Remarkably, the effects of exercise on MDD seem to be comparable to effects of antidepressant medication (Babyak et al., 2000; Hoffman et al., 2011).

Most of these physical treatment approaches to MDD posit that the central operating mechanism is the increased intensity of activity (Ekkekakis, 2003). It is proposed that the low activity level, which is characteristic for depressed individuals, should by increased to achieve the positive effects of exercises. However, in addition to a generally low level of activity, depressed individuals often show a number of further motoric characteristics. One central motoric characteristic of depressed individuals is a deviant gait pattern. A number of studies have shown a close relationship between walking style and depression (Bader, Bühler, Endrass, Klipstein, & Hell, 1999; Lemke, Wendorff, Mieth, Buhl, & Linnemann, 2000; Paleacu et al., 2007; Sloman, Berridge, Homatidis, Hunter, & Duck, 1982; Sloman, Pierrynowski, Berridge, Tupling, & Flowers, 1987). In a comprehensive analysis of gait characteristics in patients suffering from a current episode of major depression, for example, it has been demonstrated that patients not only showed reduced walking speed (i.e., activity level) but also smaller arm-swing amplitudes, smaller amplitude of vertical movements of the upper body, larger amplitudes of lateral body sway, and a more slumped and forward-leaning posture than

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healthy controls (Michalak et al., 2009). An analysis of speed dependent changes in gait parameters in non-clinical samples (Thorstensson, Nilsson, Carlson, & Zomlefer, 1984) makes it unlikely that gait characteristics of depressed patients are solely attributable to reduced walking speed (i.e., the intensity of walking).

A large body of basic research points to the fact that not only changes in general activity level but also more subtle motoric changes can have profound effects on emotional information processing. Under the term 'embodiment' numerous studies have shown a complex and reciprocal relationship between the bodily expression of emotion and the way in which emotional information is processed (Niedenthal, 2007; Niedenthal, Barsalou, Winkielman, Krauth-Gruber, & Ric, 2005).

The fact that emotional processes affect bodily states seems to be almost trivial. Obviously, emotions are expressed by the facial muscular system, but also in the static posture and dynamic activity of the whole body (Oberman, Winkielman, & Ramachandran, 2007; Pitcher, Garrido, Walsh, & Duchaine, 2008). More interesting are demonstrations of causal relations in the other direction. Diverse affective and cognitive processes are affected by manipulations of the muscular-skeletal system. For instance, in a seminal study Strack, Martin, and Stepper (1988) asked participants to hold a pen between their teeth, which forced them to contract the zygomaticus major muscle that is normally involved in the production of a smile. They found that the participants enjoyed cartoons more than those who were prevented from making zygomaticus contractions. Similarly, Stepper and Strack (1993) demonstrated that a slumped versus an upright sitting posture affected the way participants perceived positive feedback on a previously completed achievement test.

Bodily processes can also influence affective memory. Riskind (1983) showed that certain postures affected the ease with which participants were able to recall either pleasant or unpleasant life experience and Förster and Strack (1996) demonstrated that nodding or shaking the head influences a person's recall of positive and negative words.

Although basic research on embodiment effects on emotional information processing is flourishing, research on the effects of motoric system on processes relevant for psychopathological phenomena is largely lacking. In the current study, we manipulated participants' gait to adopt features reflecting the characteristics of happy or depressed walking behaviour using a biofeedback method. We then measured how many negative and positive words participants recalled from a previously presented list of items. Biased processing of self-referent material is one of the most intensively studied cognitive-affective correlates of depression. A large body of research has found that depression affects how information about oneself is processed, as evidenced by enhanced encoding and recall of negative self-referent material and by a reduced processing of positive information (Mathews & MacLeod, 2005; Matt, Vázquez, & Campbell, 1992; Williams, Watts, MacLeod, & Mathews, 1997). We expected to observe a memory bias such that manipulating the participants to walk in a more depressed way would shift recall towards relatively more negative words, and making them walk happier would bias them towards remembering relatively more positive words. Walking speed was held constant across conditions to rule out that mere differences in activity level are responsible for group differences in memory bias. We choose memory bias as our primary outcome variable because we expected that the relatively short time gait changes we aimed to induce would have effects on more subtle emotional information processes (i.e., memory bias), before effects on conscious experienced affective states could be detected. However, we also assessed the conscious affective state in order to investigate whether the linkage between motor behavior and affective processes was mediated by the explicit experience of affective states or whether the sensorimotor system can affect these functions directly before effects on conscious affect become apparent.

2. Method

2.1. Participants

A total of 47 volunteers participated in this study. All were students from Queen's University who received either course credit for their participation or a monetary compensation of $20. Data from eight of the participants were not usable due to technical problems and resulting data loss. The analysis was therefore based on data from 39 participants.

2.2. Apparatus

An optical motion capture system (17 cameras, 120 Hz sampling rate, Qualisys, Gothenburg, Sweden) was used to acquire in real time full-body movements exhibited by the participants while walking on a treadmill at a constant speed of 1.2 m/s (Troje, 2002, 2008). Data were analyzed within a 2 s temporal window according to where it scaled along a sad-happy continuum (see Supplementary Material). The continuum was parametrized in terms of a linear discriminant function which was based on the data of 14 depressive and 14 healthy participants obtained in the context of a previous study and described in more detail there (Michalak et al., 2009; Troje, 2008). An interactive animation visualizing the linear discriminant function can be viewed at http://biomotionlab.ca/Demos/BMLdepression.html. While walking on a treadmill the participants were facing a monitor mounted on a wall 4 m in front of them. On the monitor, we displayed a large gauge consisting of a horizontal scale and a vertical bar that could move along that scale. The gauge was calibrated such that the bar was located at the centre position if the participant's score was the same as during the walk exhibited at the beginning of the experiment (baseline condition, see below). From this null position the gauge deflected to the right if the participant's score indicated a happier walk and it deflected to the left if the participant's score indicated a more depressed walking pattern. In half of the participants, this relation was reversed. In either case, participants were instructed to try to walk such that the gauge would deflect to the right. The gain of the gauge was 10 cm/std (z-score relative to the distribution used to compute the discriminant function, Michalak, et al., 2009). Scores were obtained every 100 ms and the display of the gauge was updated at the same frequency. Scores were also stored in order to assess to which degree the feedback altered the participant's walk.

2.3. Instruments

To measure the effects of gait feedback on affective memory bias we adapted the self-referent encoding task (SRET, Ramel et al., 2007). In an initial encoding phase, the experimenter read out a list of 20 positive and 20 negative words (see Supplementary Material) in random order and the participants had to decide whether or not each word described them well. During a subsequent recall phase, which was applied later during the experiment and was not anticipated by the participant, they were then asked to recall as many words as possible from the entire list. Affective memory bias was measured as the difference between the number of recalled positive words and the number of recalled negative words. After participants had completed all other parts of the experiment and had stopped walking on the treadmill, they were subjected to a final questionnaire designed to assess their affective state by means of two positive (enthusiastic, interested) and three negative (sad, depressed, lonely) items from the Positive and Negative Affective Scale (PANAS, Watson, Clark, & Tellegen, 1988). The five PANAS items were presented along with 17 additional questions whose only function was to mask the true purpose of this final questionnaire. For each of the 22 questions, participants had to indicate to which degree the statements applied to them. They had the choice among five answers ranging from "very slightly or not at all" to "extremely". An example for an irrelevant masking questions is "The visual feedback display was easy to see." An example for one of the PANAS question is "I felt sad during the experiment." A complete list of the questions can be found in the Supplementary Materials.

2.4. Procedure

Upon arrival, participants were informed about the procedure and gave written informed consent as approved by the General Research Ethics Board at Queen's University. Participants were not informed about the objective of the study. They were only told that its purpose was to determine the ability of people to change their gait pattern in response to real-time feedback. Participants were randomly assigned to the depressed or happy gait feedback. They were then fitted with the motion capture suit and marker set. Subsequently, a number of demographic variables were collected: age, sex, body-mass index, and whether or not they received antidepressant medication. After a short calibration procedure, participants were asked to walk on the treadmill and they then remained walking until the end of the experiment (Fig. 1). Except for the PANAS questionnaire, all the following procedures were applied while participants were walking. Initially, participants walked for a total of 6 min to get accustomed to the setup and adopt a relaxed, natural walk. Their walking pattern was first assessed during the last minute of this period. The resulting score served as a baseline against which the effects of the subsequent manipulations was measured. It was also used to zero the gauge presented to provide feedback to the participant.

This gauge became visible to the participants at the beginning of the 7th minute on the treadmill and remained visible until the end of the experiment. Participants were instructed that their goal was to make the gauge deflect to the right as far as possible, and they were encouraged to try different ways to walk in order to achieve that. Recall that half of the participants had to adopt a happier walking pattern and half a sadder pattern to succeed in this task. Participants were not informed about the objective of the experiment. Most importantly, they were not given any hint that the manipulations were linked to emotional attributes associated with gait patterns. After four minutes of walking under biofeedback conditions the encoding stage of the SRET task was applied: An experimenter read 40 terms to the participant in random order. For each word, they had to decide whether this word described them well. That part took about two minutes. For the next 8 min, participants tried to keep the gauge deflected while their scores were continuously recorded. Finally, while still walking, participants were asked to recall as many words as possible from the list they were initially presented with. It was made clear to them that it was irrelevant whether they had indicated earlier if these words described them well or not. After participants had stopped walking on the treadmill, they filled out the questionnaire containing the five PANAS items along with the 17 irrelevant questions. At the very end of the experimental session we asked participants whether they could describe what they did in order to make the gauge respond in the intended way. Only very few of them could express their strategy in words.

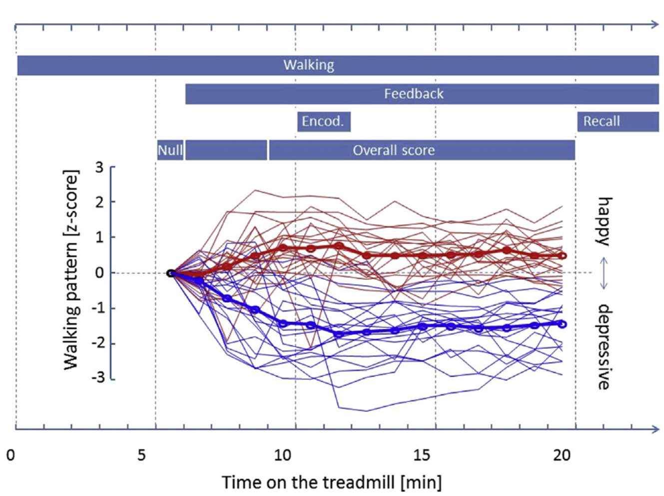

Fig. 1. The upper part depicts the time line of the experimental procedures for a single participant. Participants walked on a treadmill for a total of 23 min and moderate pace (1.2 m/s). After collecting data to null the gauge during minute 6 feedback was provided for the remaining time. The list of words was provided during the encoding phase (minutes 11–12). Participants were later asked to recall items from the list during minutes 21–23. Motion capture data were collected (minutes 6–20) and used to compute scores that provided information about their walking pattern. The lower part shows these scores averaged within 1-min bins and normalized by subtracting the data obtained during the last minute before feedback was turned on (minute 6) for individual participants (thin lines) and as a mean over all participants (thick lines). The overall score used to correlate the walking pattern with the obtained affective memory bias (Fig. 2) was based on scores obtained during minutes 10–20.

3. Results

3.1. Participants

Participant characteristics are displayed in Table 1. We found no significant differences between the two groups for any of the assessed characteristics. Informal questioning at the end of the experiment clearly showed that none of the participants had the slightest idea what the true intention of the experiment was. Specifically, they did not realize that the gauge responded to characteristics of happy versus depressed walking.

3.2. Responses to biofeedback

Scores as measured during the one-minute period before the biofeedback was introduced did not differ between the groups. Once feedback was provided, participants quickly learned to adopt a walking style that reflected the feedback they were given. In the lower part of Fig. 1 we plotted the scores for each individual participant along with the average scores of the two groups obtained in one-minute windows after subtracting from them each individual's baseline score. This baseline score reflects their walking during the first minute of recording (when no feedback was given). Gait patterns of the two groups were already significantly different in the second one-minute window after feedback was turned on (i.e. minute 8 in Fig. 1, $t(37) = 3.14$, $p < 0.01$). The

Table 1
Descriptive statistics.

	Happy gait feedback ($N = 20$)	Depressed gait feedback ($N = 19$)
Age (*M*/*SD*)	21.75 (9.60)	20.79 (2.84)
Female/Male	11/9	11/8
BMI (*M*/*SD*)	24.10 (3.97)	22.61 (2.47)
ADM (yes/no)	2/18	1/18

Note. BMI = Body Mass Index; ADM = Antidepressant medication.

difference increased for another two minutes, after which it remained stable for the rest of the experimental trial.

3.3. Affective memory bias

Participants in the happy gait feedback condition on average recalled 6.00 (SD = 2.36) positive words and 3.80 (SD = 1.67) negative words, while participants in the depressed feedback condition on average recalled 5.47 (SD = 2.23) positive words and 5.63 (SD = 2.89) negative words. We found a significant difference in the affective memory bias between the two groups ($t(37) = 2.45$, $p = 0.021$). The difference between the number of recalled positive words and the number of recalled negative words was on average 2.20 (SD = 3.00) for participants who were manipulated to walk more happily and −0.16 (SD = 3.13) for participants who were manipulated to walk with a more depressed pattern.

The relation between walking style and memory bias becomes even more remarkable when we regress the memory bias on the overall score of the walking patterns obtained by averaging all scores after participants reached a stable gait pattern (minutes 10–20). Fig. 2 visualizes the number of recalled negative and positive word counts as a function of their walking pattern. The length and direction of the arrows connecting the two data points illustrates the affective memory bias as expressed by the difference between the positive and negative recalled words. The happier the person walks the higher is the affective memory bias ($r = 0.49$, $F(1,37) = 11.53$, $p < 0.01$). A closer look at the number of recalled positive and negative words shows that the difference score is entirely carried by the number of recalled negative word ($F(1,37) = 12.8$, $p < 0.001$), which decreases by more than a factor 3 between participants walking in the most depressed manner and those who walk with the most happy walking style. The number of recalled positive words did not contribute significantly to the affective memory bias ($F(1,37) = 0.75$, n.s.).

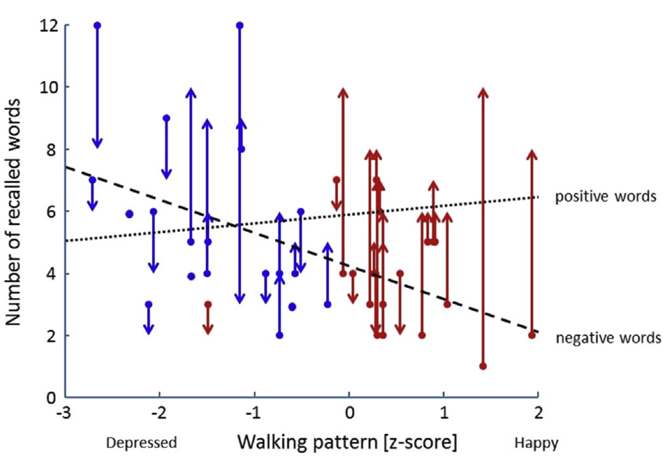

Fig. 2. Dependency of the affective memory bias (difference between positive and negative recalled words) on the walking pattern. The latter is expressed in z-scores with respect to the distribution within the population used to create the happy-depressed discriminant function (see Michalak et al., 2009 for details). Positive values indicate happy walking and negative values sad walking. The length and direction of the arrows connecting the two data points illustrates the affective memory bias as expressed by the difference between the positive and negative recalled words for individual participants. Disks at the base of the arrow indicate number of recalled negative words and arrow heads at the end indicate number of recalled positive words. The dashed and dotted lines indicate the linear regressions describing the number of recalled negative and positive words, respectively, as a function of the walking pattern. Data shown in blue are from participants who were manipulated to walk more depressed, and data in red from those who walked more happily. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

In a second step we investigated whether the effect of gait feedback on memory bias was mediated by self-reported affective state. Mood ratings did not significantly differ between the depressed and happy gait feedback condition (positive affect: $t(37) = -0.65$, $p = 0.523$; negative affect: $t(37) = 1.420$, $p = 0.164$). Next, while analysing the effects of gait feedback on memory bias we controlled for mood ratings of participants using an ANCOVA (all five PANAS items were included as independent covariates). The significant effect of gait feedback on affective memory bias remained intact ($F(1,32) = 4.46$, $p = 0.043$) indicating that direct mediation by the participant's explicit affect played only a minor role, if any at all.

4. Discussion

The aim of the present study was to investigate the effects of changes in gait patterns on affective memory bias. Participants received online gait feedback, which altered their gait pattern towards a walking pattern that resembled the one of individuals who were either happier than normal or more depressed than normal. We hypothesized that participants would recall relatively more negative words when walking in a depressed manner and relatively more positive words when walking in a more happy way.

We found that memory for negative words did in fact change substantially with walking pattern. We also observed a change for memory for positive words in the expected direction, but the change was very small and did not withstand statistical analysis. Our results show that biased memory towards self-referent negative material can be changed by manipulating the style of walking.

What caused the observed change in memory bias? Recall, that participants were not informed about the intention of the experiment and the fact that the gauge responded to signatures that characterize happy or sad walking. Informal questioning at the end of the experiment also did not reveal any clue whatsoever that would indicate that they had learned about it over the course of the experiment. Explicit knowledge about the motivation of experiment or the semantic contents of the walking pattern they adopted cannot account for our findings.

The question remains whether the effect of walking on memory bias was mediated directly by somatic systems, or whether the walking pattern induced a change in emotional state, which then, in turn, affected memory constellation. The PANAS questions that we hid within a larger list of questions revealed no indication for changes in emotional or affective state as a result of the way participants walked. Correspondingly, our data support the idea that the induced changes in affective memory bias were directly caused by somatic processes. Candidates are, for instance, efference copies from the motor system or somato-sensory input triggered by the adopted postures and movement patterns. However, it should be noted that the emotional state was assessed after the gait feedback phase, so we cannot role out that the affective state during walking might have affected memory bias.

Taken as a whole, our results indicate that manipulating walking style can change a central pathological mechanism of MDD, namely biased processing of negative self-referent material. It should be noted that walking speed was held constant across conditions. Correspondingly, we can rule out that effects of gait manipulation on memory bias are attributable to differences in activity level between groups. Our findings indicate that, as the Interacting Cognitive Subsystems (ICS) approach of Teasdale and Barnard (1993) proposes, a so-called 'depressive interlock configuration' between bodily (e.g., gait patterns) and cognitive (e.g., affective memory bias) feedback loops might become established that lock the two subsystems into a self-perpetuating pathological configuration.

However, it should be noted that one limitation of our study is that effects of gait manipulation were investigated in a non-clinical group of undergraduate students. In a recent study Michalak, Mischnat, and Teismann (2014) have shown that body manipulations (i.e., changes in posture) have effects on memory bias in depressed inpatients. However, to draw stronger conclusions about the clinical relevance of gait feedback, futures research should investigate effects of gait feedback in patients suffering from MDD.

A further limitation of our study was that the experimenter who delivered the spoken list of 40 emotional words was not blind to the walking condition that the participant was in. To strictly rule out that paralinguistic cues affected the results in any subtle way, future research should use blinded experimenters or a word list displayed by an audiotape. Moreover, in future studies effects of gait changes on conscious affective state should be investigated in more detail. It can be speculated that the short period we used in our study to manipulate gait, the relatively small sample size and the use of a reduced version of the PANAS has made it difficult to detect effects of gait manipulation on self-reported affect. Therefore, future studies should use more extensive gait manipulation, lager samples and the total PANAS to detect effects of gait manipulations on affect.

In summary, the results of our study indicate, that changes in gait pattern affects the way people process negative and positive material. Our findings might also have practical implications. In addition to changing the general activity level by prescribing exercises it might be worthwhile to pay attention to other habitual motoric characteristics of patients suffering from MDD. Changing the walking style of depressed people might help to de-escalate pathological vicious circles between bodily and emotional processes that maintain depression. Future research will have to show, whether gait-dependent biofeedback is in fact an effective treatment option for patients suffering from depressive disorders.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jbtep.2014.09.004.

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