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# Implicit memory for emotional words is modulated by cardiac perception

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ABSTRACT

In the present study we investigated the impact of viscero-sensory feedback on memory performance. Participants with good and poor perception of their heart activity were presented with positive, negative and neutral words while heart rate and skin conductance were measured. After a distractor task, participants were asked to complete primed and unprimed wordstems. Implicit memory performance was assessed in terms of accuracy of completion. In our study, participants with good cardiac perception completed significantly more wordstems of previously presented positive and negative words, whereas no group differences were found for wordstems of neutral words and physiological measures during encoding. Our findings document a substantial role of visceral feedback in implicit memory processes. They are in line with Damasio's somatic marker hypothesis stating that access to information about somatic processes facilitates cognitive processing.



## 1. Introduction

It is well established that psychological and physiological events can either enhance or impair the formation of memories. Several studies have demonstrated that emotional material is better remembered than neutral material (Bradley et al., 1992; Buchanan et al., 2006; Bush and Geer, 2001; Dolcos and Cabeza, 2002; Kensinger and Corkin, 2003). Furthermore, the arousal induced by emotional events has also been shown to facilitate subsequent memory (Cahill et al., 1996; Cahill and McGaugh, 1998; Cuthbert et al., 2000; Dolcos et al., 2003, 2004). Physiological measures such as skin conductance responses (SCRs) and heart rate (HR) have usually been applied as indices of arousal. Both increased SCRs as well as increased HR responses to emotionally arousing stimuli exhibited a strong correspondence with subsequent memory recall of those stimuli (Bradley et al., 1992; Jennings and Hall, 1980). Furthermore, pharmacological agents (e.g. epinephrine) which enhance sympathetic action by increasing arousal and heart rate produce memory enhancement (Cahill and McGaugh, 1998), whereas β-adrenergic antagonists (e.g. β-blockers) which inhibit sympathetic action by reducing arousal and heart rate cause memory impairment (Cahill and Alkire, 2003; van Stegeren et al., 1998). Presumably, the stimulation of peripheral β-adrenergic receptors during emotionally arousing events modulates the HR changes (Cahill and McGaugh, 1996). Emotionally arousing events lead to the release of hormonal substances such as adrenalin which activate peripheral receptors located on vagal afferents and in this manner initiate signals to the brain carried by the vagus. Several studies using vagotomy (Flood et al., 1987; Nogueira et al., 1994) or reversible inactivation of the nucleus of the solitary tract (Williams and McGaugh, 1993), the primary relay site of vagal afferents in the brain, have demonstrated impaired memory formation. In contrast, electrical stimulation of the vagus nerve as used to suppress epileptic seizures has been shown to enhance memory retention (Clark et al., 1999). In addition to increased HR, an initial HR deceleration within the first seconds during stimulus presentation can also predict subsequent memory enhancement (Abercrombie et al., 2008; Buchanan et al., 2006). This initial HR deceleration reflects an orienting response involving attentional processing which may operate preparatory for cognitive functioning (Cook and Turpin, 1997). Taken together, these findings suggest that cardiovascular responses play a crucial role in cortical sensitivity to stimuli via afferent connections from the heart to the brain (Öhman et al., 2000).

Based on the finding that afferent information from the heart affects cognitive processes, it would seem likely that individuals with more precise access to signals from the heart show enhanced memory performance. The perception of sensations associated with the activity of the heart is referred to as "cardiac perception" (e.g. Brener and Kluvitse, 1988; Critchley et al., 2004; Schandry, 1981; Wiens et al., 2000). A variety of methods for the quantification of cardiac perception have been developed. The two principal types are tracking and discrimination paradigms. Tracking paradigms comprise procedures in which participants are instructed to press a button or tap a finger in time to the rhythm of their heartbeats (e.g. McFarland, 1975), or in which participants have to count their heartbeats during a certain period of time (e.g. Carroll and Whellock, 1980; Schandry, 1981). The most widely used procedure is the mental tracking task proposed by

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Schandry (1981). In this paradigm, participants count their heartbeats silently during three different time intervals lasting less than a minute each. During the intervals, participants are asked to concentrate on their heartbeats and are not permitted to take their pulse or to attempt any other physical manipulations that could facilitate the detection of heartbeats. Sensitivity to heartbeat sensations is indexed by a score based on the absolute value of the difference between the number of counted heartbeats and the number of actual heartbeats. Whereas tracking tasks involve only attention to the participants' heartbeats, discrimination paradigms require a decision as to whether an externally presented series of stimuli is related in a certain way to the sequence of one's own heartbeats (e.g. Brener and Jones, 1974; Brener and Kluvitse, 1988; Whitehead et al., 1977). For instance, two types of series of external stimuli may be presented: a series of external stimuli (lights, tones or vibrating stimuli), which match the heartbeats (S+ stimuli) and a series without any temporal relation to heartbeats (S− stimuli). Participants have to decide which of these two signal sequences matches their own heartbeats. The discrimination ability is used as an index of cardiac perception. The ability to perceive cardiac signals varies to a substantial degree among individuals depending on gender, percentage of body fat and physical fitness (Cameron, 2001; Jones, 1994; Katkin, 1985; Schandry and Bestler, 1995; Vaitl, 1996). Furthermore, differences in cardio-dynamic parameters such as stroke volume and blood pressure also contribute to differences in cardiac perception (O'Brien et al., 1998; Schandry and Bestler, 1995). Recent research has identified the neural correlates of cardiac perception. Functional MRI and EEG studies have revealed enhanced neural activity in the insula, the somatomotor and anterior cingulate cortex during performance in a heartbeat perception task (Critchley et al., 2004; Pollatos et al., 2005a, 2007d). Furthermore, heartbeat perception accuracy correlated with activity in the right insular cortex (Critchley et al., 2004).

Research on cardiac perception over the past few decades has focused on emotional processing. Several studies have shown that in individuals with good cardiac perception emotional experience is enhanced (Barrett et al., 2004; Herbert et al., 2007; Pollatos et al., 2007a,c; Schandry, 1981; Wiens et al., 2000). These findings support classic theories of emotion, as proposed by James (1884), who suggested that interoception is an important factor in emotion processing. Also, in recent concepts of emotion, based on modern neuroscientific findings, perception of bodily signals is posited to mediate emotional experience (cf. Bechara and Naqvi, 2004; Craig, 2003, 2004; Damasio, 1994, 1999; Thayer and Lane, 2000). One prominent concept is Damasio's somatic marker hypothesis (Damasio, 1994, 1999), which suggests that somatic information guides emotional and cognitive processes. This hypothesis states that each event is associated with specific somatic responses (e.g. heart rate, skin conductance, tonicity), the so-called somatic markers, which are evoked by the consequences of this event. The ventromedial prefrontal cortex is thought to coordinate external stimulus information with internal information about emotion-based body states, provided by brainstem nuclei, somatosensory and insular cortex, and the amygdala. When a new situation arises which is similar to one experienced in the past, these associated somatic responses are reactivated and guide individuals in their emotional and cognitive processes.

A growing body of evidence supports the idea that somatic states related to emotion are involved in cognitive processes (Bechara et al., 1997, 2000; Damasio, 1994, 1999; Matthias et al., 2009; Pollatos and Schandry, 2008; Werner et al., 2009). Bechara et al. (1994, 1996, 1999) showed that patients with lesions in the ventromedial prefrontal cortex, which functions as an interface for representing and regulating somatic markers, exhibit deficits in decision-making in spite of otherwise normal cognitive functioning. Whereas these studies focused on a weak or missing representation of somatic responses, Werner et al. (2009) investigated individuals who have accurate access to their bodily signals. They demonstrated that good cardiac perception was associated with superior decision-making performance in a complex and uncertain situation as simulated by the Iowa Gambling Task. Recently, Pollatos and Schandry (2008) investigated the relationship between cardiac perception and memory recall of emotional pictures. Cardiac perception was related to increased cardiovascular reactivity to emotional stimuli and in this manner modulated memory performance. However, they were not able to disentangle the contribution of cardiovascular activity and cardiac perception on memory performance. Pollatos and Schandry investigated explicit memory. Explicit memory stores contents which can be described semantically and can be retained explicitly. In contrast, in implicit memory learning processes, such as learning of motor or cognitive abilities or priming, are not carried out intentionally and are not affected by conceptual processes, suggesting that somatic responses in particular may be relevant in implicit memory processing.

In the present study, we aimed to investigate whether bodily perception affects implicit memory. We adopted the wordstem completion task, which is a well-established experimental paradigm for investigating implicit memory (e.g. Harrison and Turpin, 2003; Richards and French, 1991). Based on the somatic marker theory we hypothesized that in individuals with good cardiac perception, who have more precise access to somatic feedback, the perception of the arousal induced by emotional words is enhanced. This perception will improve memory performance for emotional material. Thus, we predicted that participants with good cardiac perception complete more primed wordstems of words with emotional content than participants with poor cardiac perception.

## 2. Material and methods

### 2.1. Participants

Thirty participants with good cardiac perception and 30 participants with poor cardiac perception took part in the study (for details of the quantification of cardiac perception see below). All participants were screened for health status using an anamnestic questionnaire. They were only included if they did not suffer from any physical or psychiatric diseases and did not use psychoactive drugs or medication affecting the cardiac or respiratory systems. All participants gave written informed consent and received financial remuneration of €15.

The groups with good and poor cardiac perception were matched according to age and body mass index. The good cardiac perception group consisted of 15 female and 15 male participants. The poor cardiac perception group comprised 17 female and 13 male participants. Both groups showed a comparable level of education (good cardiac perception: university-entrance diploma $n = 30$; poor cardiac perception: university-entrance diploma $n = 29$, secondary school certificate $n = 1$). In the good cardiac perception group 28 of the participants were university students and 2 were in the workforce. In the poor cardiac perception group 24 of the participants were university students and 6 were in the workforce. Sample characteristics are shown in Table 1.

To control for the impact of affective states on memory performance we assessed trait and state anxiety using the State-Trait-Anxiety Inventory (STAI, Spielberger et al., 1983). Both the trait and the state scale consist each of 20 statements describing habitual or current feelings of anxiety, respectively. Participants with good and poor cardiac perception did not differ in trait or state anxiety (see Table 1).

### 2.2. Wordstem completion task

Participants performed a wordstem completion task to assess implicit memory. For this task, a list consisting of 60 words was compiled including 20 positive adjectives, 20 negative adjectives and 20 neutral adjectives. The words were drawn from the word battery of Herbert et al. (2008) who asked participants to rate 500 adjectives on the Self-Assessment Manikin scale (SAM, Bradley and Lang, 1994) according to valence and arousal. Positive words were chosen if they were high on pleasantness (mean normative rating of valence (SAM scale 9-point Likert-scale): $M = 7.27$, $SD = 0.34$), negative words were chosen if they were low on pleasantness (mean normative rating of valence (SAM scale 9-point Likert-scale): $M = 2.17$, $SD = 0.38$), and neutral words were selected from those words found to be in the middle range of pleasantness (mean normative rating of valence (SAM scale 9-point Likert-scale):