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Research Report

Darwin revisited: The vagus nerve is a causal element in controlling recognition of other's emotions

Lorenza S. Colzato [a,b,c,*], *Roberta Sellaro* [a] *and Christian Beste* [d]

[a] *Leiden University, Cognitive Psychology Unit, Leiden Institute for Brain and Cognition, Leiden, The Netherlands*
[b] *Department of Cognitive Psychology, Institute of Cognitive Neuroscience, Faculty of Psychology, Ruhr University Bochum, Bochum, Germany*
[c] *Institute for Sports and Sport Science, University of Kassel, Kassel, Germany*
[d] *Cognitive Neurophysiology, Department of Child and Adolescent Psychiatry, Faculty of Medicine of the TU Dresden, Dresden, Germany*

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ABSTRACT

Charles Darwin proposed that via the vagus nerve, the tenth cranial nerve, emotional facial expressions are evolved, adaptive and serve a crucial communicative function. In line with this idea, the later-developed polyvagal theory assumes that the vagus nerve is the key phylogenetic substrate that regulates emotional and social behavior. The polyvagal theory assumes that optimal social interaction, which includes the recognition of emotion in faces, is modulated by the vagus nerve. So far, in humans, it has not yet been demonstrated that the vagus plays a causal role in emotion recognition. To investigate this we employed transcutaneous vagus nerve stimulation (tVNS), a novel non-invasive brain stimulation technique that modulates brain activity via bottom-up mechanisms. A sham/placebo-controlled, randomized cross-over within-subjects design was used to infer a causal relation between the stimulated vagus nerve and the related ability to recognize emotions as indexed by the Reading the Mind in the Eyes Test in 38 healthy young volunteers. Active tVNS, compared to sham stimulation, enhanced emotion recognition for easy items, suggesting that it promoted the ability to decode salient social cues. Our results confirm that the vagus nerve is causally involved in emotion recognition, supporting Darwin's argumentation.

* *Corresponding author*. Leiden University Institute for Psychological Research, Cognitive Psychology Unit, Wassenaarseweg 52, 2333 AK Leiden, The Netherlands.
E-mail address: colzato@fsw.leidenuniv.nl (L.S. Colzato).
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1. Introduction

In his seminal book "The Expression of Emotions in Man and Animals" (1872/1965), Darwin was the first to propose that emotion expressions are controlled by a bidirectional neural communication between the heart and the brain via the so-called "pneumogastric" nerve. Nowadays known as the vagus nerve, this is the tenth cranial nerve and represents a key component of the parasympathetic nervous system. Notably, the vagus nerve is the longest cranial nerve. Given that it passes via the neck and thorax to the abdomen, the vagus nerve has the broadest distribution in the body. It comprises somatic and visceral afferent fibers, as well as general and special visceral efferent fibers. According to Darwin, emotional facial expressions are evolved and adaptive and serve a crucial communicative function. Unfortunately, at that time, the understanding of the neuroanatomy and phylogeny of the nervous system was limited and Darwin's intuition has been further developed only a century later by Porges (2001; 2003; 2007) in his influential polyvagal theory. This theory proposes that the vagus nerve is the key phylogenetic substrate that regulates emotional and social behavior. Interestingly, mammals are the only vertebrates characterized by a myelinated vagus that can rapidly regulate the nervous system to foster engagement and disengagement with the environment. According to the polyvagal theory two functionally distinct branches of the vagus fulfill different evolutionary responses in mammals. Whereas, the more primitive branch (The Dorsal Vagal Complex) is supposed to provoke immobilization behaviors (e.g., feigning death), the more evolved branch (The Ventral Vagal Complex) has been proposed to be related to social communication and self-soothing behaviors (Porges, 2001; 2003; 2007). The polyvagal theory assumes that optimal social interaction, which includes the recognition of emotion in faces, is modulated by the vagus nerve. In line with this idea, it has been found that the vagal tone (as indexed by heart rate variability) is a reliable marker of one's ability to respond to and recognize social cues: resting-state heart rate variability was positively associated with performance on Reading the Mind in the Eyes Test (RMET) (Quintana, Guastella, Outhred, Hickie, & Kemp, 2012). The RMET requires participants to assess someone's emotions based on images of the eye region and performance on this test has been found to be poor among patients suffering from pathologies associated with dysfunction of the vagus nerve, such as autism (Baron-Cohen, Wheelwright, Hill, Raste, & Plumb, 2001) and depression (Lee, Harkness, Sabbagh, & Jacobson, 2005). Unfortunately, the nature of the studies outlined above is correlative and, so far, in humans it has not yet been demonstrated that the vagus nerve plays a causal role in emotion recognition.

The aim of the current study therefore is to examine the causal involvement of the vagus nerve and the recognition of someone's emotions based on images of the eye region, as indexed by the RMET. In order to do that, we employed transcutaneous (through the skin) vagus nerve stimulation (tVNS), a novel non-invasive brain stimulation technique that modulates brain activity via bottom-up mechanisms (Ventureyra, 2000). That is, the propagation of the afferent signal from the vagus nerve travels from peripheral nerves toward the brain stem and from there to higher cortical structures (Shiozawa et al., 2014; Vonck et al., 2014). As pointed out by Shiozawa et al. (2014) the vagus nerve innervates the nucleus tractus solitarious bilaterally, which is connected to the locus coeruleus. tVNS, proposed for the first time by Ventureyra (2000), is safe and accompanied only by minor side effects such as tingling or itching sensation under the electrodes. Several studies employing high intensity tVNS have not revealed any major side-effects (Dietrich et al., 2008; Kraus et al., 2007; Bauer et al., 2016). Given the right vagal nerve has efferent fibers to the heart, tVNS is safe to be performed only in the left ear (Kreuzer et al., 2012). tVNS acts via the auricular branch of the vagus nerve (ABVN) which supplies the skin of the concha in the human ear (Peuker & Filler, 2002) allowing for a reliable transcutaneous electrical stimulation of the nerve fibers in this area. The stimulation activates the thick-myelinated Aβ fibers of the ABVN which project directly to the nucleus of the solitary tract in the brainstem.

Following Kraus et al. (2007), a clever way to create a sham condition using tVNS is by attaching the stimulation electrodes to the center of the left ear lobe, which is free of cutaneous vagal innervation, see Fig. 1 (Peuker & Filler, 2002). By doing this, the participants perceive the exact same minor side effects of the active stimulation and they are not able to disentangle the active from the sham stimulation.

In contrast to imaging techniques, which are only correlational, by means of tVNS we are able to infer a causal relation between the stimulated vagus nerve and the related ability to recognize emotions as indexed by performance on the RMET (van Leusden, Sellaro, & Colzato, 2015). tVNS has been found to reliably activate the vagus nerve. In a seminal study Fallgatter et al. (2003) stimulated the tragus and demonstrated, by means of early acoustic evoked potentials, that active tVNS, compared to sham, produced a clear and reliable vagus sensory evoked potential in healthy participants. Further, two functional magnetic resonance imaging (MRI) studies in healthy humans have found that tVNS increased activation in the brainstem region including the locus coeruleus and nucleus of the solitary tract, indicating that tVNS is able to effectively stimulate vagal afferents to the brainstem (Dietrich et al., 2008; Frangos, Ellrich, & Komisaruk, 2015).

In sum, if the vagus nerve is involved in the process of emotion recognition as hypothesized by Darwin (1872/1965) and Porges (2001; 2003; 2007), we would expect that active tVNS, compared to sham stimulation, will enhance performance of the recognition of someone's emotions based on images of the eye region.

2. Material and methods

2.1. Participants

Thirty-eight Leiden University undergraduate students (30 females, 8 males, mean age = 22.29 years, range 18–26) participated in the experiment. Participants were recruited via