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Original Article

Effects of Transcutaneous Auricular Bilateral Vagus Nerve Stimulation on Social Cognition

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Abstract

Objectives: This study aims to examine the effects of transcutaneous auricular vagus nerve stimulation (taVNS) on social cognition. The research aims to investigate the effects of transcutaneous auricular vagus nerve stimulation (taVNS) on social cognition, specifically focusing on its potential to enhance social cognition abilities, strengthen the relationship between social skills, and influence the connection between Theory of Mind (ToM) and empathy.

Methods: One hundred volunteers (50 female, 50 male), aged between 18 and 45 years, with no psychiatric conditions and who were suitable for vagus nerve stimulation, participated in the study. An intergroup design was employed, with participants first completing a social interest scale. The experimental group received taVNS stimulation, while the control group received sham stimulation. After a 20-minute stimulation period, participants completed the Reading the Mind in the Eyes Test (RMET) and the Questionnaire of Cognitive and Affective Empathy (QCAE).

Results: The ToM results showed improvement with taVNS. However, no significant differences were observed between groups for empathy scores, except in the peripheral responsivity subdimension, where the experimental group scored lower than the control group.

Conclusion: According to polyvagal theory, activation of the parasympathetic nervous system promotes a sense of safety, thereby fostering social engagement. A bidirectional relationship exists between vagal activity and social behavior. The results indicate that increased vagal activation enhanced participants' theory of mind (ToM). This sense of security frees cognitive resources, allowing individuals to focus on understanding others' mental states rather than self-protection. taVNS appears to improve theory of mind but has no significant effect on empathy or its subdimensions, except for peripheral responsivity.

Keywords: Empathy, social cognition, tavns, theory of mind, vagus nerve stimulation.

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Belonging to a social group is a fundamental survival strategy. Social groups provide resources such as food, protection from external threats, and care during illness. However, being part of a social group requires specific skills, including the ability to understand and respond appropriately to others. Social cognition encompasses the abilities required to interpret and navigate our social environment, including theory of mind (ToM), empathy, joint attention, and the understanding of sarcasm. This study focuses on examining empathy and ToM as key social cognition skills.

According to polyvagal theory, the development of the autonomic nervous system plays a crucial role in socialization.[1] Phylogenetic changes in the autonomic nervous system led to the development of advanced social behaviors. Notably, the myelination of the vagus nerve facilitated new social capabilities, enabling more effective interactions and

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understanding between individuals. The autonomic nervous system continuously monitors our environment, triggering appropriate responses to maintain social harmony.[2]

The vagus nerve, the 10th cranial nerve, plays a pivotal role in the parasympathetic branch of the autonomic nervous system. It establishes a bidirectional communication pathway between the brain and various internal organs.[3] Porges[4] emphasized the significance of the vagus nerve in social behavior, proposing that its activation enhances social cognition. Several methods can manipulate the parasympathetic nervous system, including breathing exercises,[5] meditation,[6] and vagus nerve stimulation (VNS).[7]

VNS was initially developed as an invasive treatment for epilepsy in 1998, with noninvasive versions later emerging for use in various other conditions.[8]

In this study, we employed transcutaneous auricular VNS (taVNS). While the precise mechanism of action remains unclear, research suggests that taVNS is a safe and effective tool for enhancing parasympathetic activation.[9]

This study investigates the effects of taVNS on social cognition, with three main objectives: (1) to explore the relationship between taVNS and ToM, (2) to examine the relationship between taVNS and empathy, and (3) to assess how taVNS influences the connection between ToM and empathy.

Materials and Methods

Participants

A total of 100 participants (50 women and 50 men) voluntarily participated in the study. Participants ranged in age from 18 to 45 years, with a mean age of 29.10 years (Standard deviation [SD] = 7.072). The inclusion criteria required participants to meet safety requirements for VNS, with exclusions made for individuals with specific medical conditions, including pregnant individuals, those with active implants (e.g., cochlear implants, vagus nerve stimulators, or pacemakers), or those with certain medical conditions such as sleep apnoea, hypotension, bradycardia, hypoglycemia, and others.[10]

Individuals with prior experience in meditation or breathing exercises and those with psychiatric disorders were also excluded, as these factors could influence the parasympathetic nervous system. All participants were naive to taVNS.

Instruments

Demographic information form

This form collected basic information about participants, including gender, age, education level, family size, and number of siblings, and also served as a checklist for exclusion criteria.

Reading the mind in the eyes test (RMET)

Developed by Baron-Cohen et al.[11] and adapted into Turkish by Yıldırım et al.,[12] this test is widely used to measure ToM. It consists of 32 images depicting the eye regions of different individuals, with participants selecting one of four options to describe the mental state of the person in the image. The test's reliability was assessed using the Kuder-Richardson 20 test (KR20=0.72), and test–retest reliability was determined via the Bland-Altman method, with a confidence interval of X±2SD (lower limit: -6.68, upper limit: +6.43).

Cognitive and emotional empathy questionnaire (Questionnaire of cognitive and affective empathy [QCAE])

Developed by Reniers et al.[13] and translated into Turkish by Gıca et al.,[14] this scale assesses an individual's empathy level. It consists of 31 Likert-style questions, with subdimensions including perspective-taking, online simulation, emotional contagion, proximal responsivity, and peripheral responsivity. Internal consistency for both the initial and retest measurements was calculated using Cronbach's alpha values, ranging from 0.50 to 0.82 for the first test, and 0.46–0.88 for the retest.

Vagustim

Vagustim is a noninvasive device used to stimulate the vagus nerve through the auricular canal, providing parasympathetic activation via electrical pulses. The device was applied bilaterally with conductive gel to both ears, and the electrodes were positioned correctly. The threshold value for each participant was determined, and the stimulation lasted for 20 min. The modulation mode was used for this research, with a width set at 300 ms and a rate of 10 Hz.[15]

Procedure

Participants who volunteered to participate filled out an informed consent form. Those who met the inclusion criteria completed the demographic form, which also served as a checklist for exclusion criteria. Participants were randomly assigned to either the taVNS (experimental) group or the sham (control) group.

In the taVNS group, conductive gel and electrodes were applied, and stimulation was delivered for 20 min using the modulation mode at 300 ms width and 10 Hz speed. In the control group, the same procedure was followed, but no stimulation was administered.

After the stimulation, participants completed the RMET and QCAE. Participants were then asked to report any discomfort or side effects they may have experienced.

The study was approved by the Non-interventional Clinical Research Ethics Committee of İstanbul Medipol University on

Table 1. Comparison of QCAE scale subscale averages in experimental and control groups

	Group	n	$\bar{X}$	SD	t	p[1]
Perspective	Control	50	2.820	0.522	-0.370	0.712
Taking	taVNS	50	2.856	0.453		
Online	Control	50	2.582	0.487	-0.567	0.572
Simulation	taVNS	50	2.663	0.407		
Emotional	Control	50	2.950	0.713	-0.085	0.932
Contagion	taVNS	50	2.962	0.652		
Proximal	Control	50	3.105	0.585	-0.390	0.697
Liability	taVNS	50	3.149	0.554		
Peripheral	Control	50	2.630	0.579	2.737	0.046*
Responsivity	taVNS	50	2.457	0.419		
QCAE	Control	50	2.817	0.435	0.080	0.936
Total	taVNS	50	2.811	0.363		

*: p<0.05. [1]: Independent sample t-test p-value. QCAE: Questionnaire of cognitive and affective empathy, SD: Standard deviation, t: t value, taVNS: Transcutaneous auricular VNS.

Table 2. Comparison of the RMET scale subscale averages in the experimental and control groups

	Group	n	$\bar{X}$	SD	t	p[1]
Easy	Control	50	9.6200	2.07895	-2.958	0.004**
Questions	taVNS	50	10.9031	2.29458		
Difficult	Control	50	11.1200	2.02676	-4.798	0.000**
Questions	taVNS	50	13.0000	1.93015		
RMET	Control	50	20.7400	3.49232	-4.493	0.000**
Total	taVNS	50	23.9038	3.61511		

*: p<0.05, **: p<0.01. [1]: Independent sample t-test p-value. RMET: The reading the mind in the eyes test

September 14, 2023, with approval number 742. All procedures followed were in accordance with ethical standards, including the Declaration of Helsinki, and applicable regulations.

Statistical Analysis

Data were analyzed using Statistical Package for Social Sciences 25.0 software. The RMET scores were divided into easy and difficult questions based on previous research.[16] The accuracy rates of each question in the test development article were taken as the basis for the division into two processes.[1]

Independent samples t-tests were used to compare scores on the RMET and QCAE scales. Pearson correlation tests were applied to examine relationships between the QCAE and RMET scores.

Results

Comparison of the Cognitive and Affective Empathy Questionnaire (QCAE)

No significant differences were found between the groups on the total score of the QCAE or its subscales, including perspective-taking, online simulation, emotional contagion, and proximal responsivity (p>0.05). However, a significant difference was observed in the peripheral responsivity subscale, with the experimental group (2.457±0.419) scoring lower than the control group (2.630±0.579) (p<0.05) (Table 1).

Comparison of the RMET

Significant differences were found in the RMET total score as well as in the easy and difficult question subscales (p<0.05). The experimental group scored higher than the control group, with the experimental group achieving a total score of 23.90 (±3.61) compared to 20.74 (±3.49) in the control group. In the easy questions subscale, the experimental group scored 10.90 (±2.29), while the control group scored 9.62 (±2.08). Similarly, in the difficult questions subscale, the experimental group scored 13.00 (±1.93) compared to 11.12 (±2.03) in the control group (p<0.01) (Table 2).

Examining Relationships Between the QCAE and RMET Scores

Pearson correlation tests revealed no significant relationships between the RMET and QCAE scores in the control group. However, in the experimental group, a

Table 3. Examining the relationships between variables in the experiment and control groups

	taVNS		Control	
	QCAE	RMET	QCAE	RMET
QCAE	1	1		
RMET	0.315**	1	-0.019	1

**: p<0.01 pearson correlation. taVNS: Transcutaneous auricular VNS, QCAE: Questionnaire of cognitive and affective empathy, RMET: The reading the mind in the eyes test

positive significant relationship was detected between the QCAE and RMET scores (r=0.315, $p<0.05$) (Table 3).

Discussion

The influence of the parasympathetic nervous system on ToM is well-documented. Previous research has shown that individuals with higher parasympathetic activity tend to perform better on ToM tasks.[17,18] Our findings support this, as the experimental group demonstrated significant improvements in ToM, particularly in both easy and difficult RMET items. As hypothesized, taVNS seems to enhance ToM by increasing parasympathetic activation, thereby allowing participants to focus on understanding others' mental states rather than self-protection.

Research has also suggested a relationship between empathy and the parasympathetic nervous system.[19,20] While we anticipated significant differences in empathy between the experimental and control groups, our findings did not fully align with this expectation. Although the experimental group scored lower on the peripheral responsivity subscale, no other significant differences were observed. This discrepancy may be attributed to the specific method used to assess empathy. Future research should explore alternative methods for measuring empathy in relation to vagal tone to confirm these results.

This study provides preliminary evidence that taVNS can enhance social cognition, particularly ToM, by promoting parasympathetic nervous system activation. However, further studies with larger sample sizes and alternative empathy assessments are needed to better understand the effects of taVNS on social cognition.

Disclosures

Ethics Committee Approval: The study was approved by the İstanbul Medipol University Non-interventional Clinical Research Ethics Committee (no: 742, date: 14/09/2023).

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