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INTEROCEPTIVE CORTICAL HEMODYNAMICS IN HEALTHY INDIVIDUALS AND PATIENTS WITH DISORDERS OF CONSCIOUSNESS: A PILOT STUDY

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ABSTRACT

Aim: The aim of this pilot study was to investigate cortical oxyhemoglobin (HbO) responses measured by functional near-infrared spectroscopy (fNIRS) during resting state and a heartbeat counting task in healthy individuals and patients with disorders of consciousness (DoC). The study sought to provide preliminary insights into the relationship between interoceptive processes and mechanisms of consciousness, and to contribute to the development of biomarkers independent of behavioral measures.
Materials and Methods: Thirteen healthy individuals and six DoC patients, matched for age, sex, and education, were included. fNIRS measurements were obtained from frontal and parietotemporal regions using a 35-channel NIRScout device. Resting-state recordings consisted of 7 minutes with eyes closed, while interoception was assessed with Schandry's heartbeat counting paradigm. ΔHbO responses were preprocessed with Homer3 software and analyzed using non-parametric statistical tests.
Results: No significant differences were observed between groups during the resting condition. In healthy individuals, the heartbeat counting task was associated with significant decreases in ΔHbO levels in the left and mid-frontal regions. In the DoC group, no differences were found between resting and task conditions. Between-group comparisons revealed that healthy participants showed lower ΔHbO values in the left and right temporoparietal regions compared to the DoC group.
Conclusion: This pilot study demonstrated significant hemodynamic changes in frontal and temporoparietal regions during interoceptive tasks in healthy individuals, whereas no task-related responses were observed in DoC patients. Differences in the temporoparietal regions highlight their critical role in interoceptive awareness and conscious experience. Despite the limited sample size, the findings suggest that fNIRS may contribute to the development of potential biomarkers for disorders of consciousness.
Keywords: Interoceptive, Hemodynamics, Functional Near-Infrared Spectroscopy, Disorders of Consciousness

SAĞLIKLI BİREYLERDE VE BİLİNÇ BOZUKLUĞU OLAN HASTALARDA İNTEROSEPTİF KORTİKAL HEMODİNAMİ: PİLOT ÇALIŞMA

ÖZET

Amaç: Bu pilot çalışmanın amacı, sağlıklı ve bilinç bozukluğu bulunan bireylerde dinlenim ve kalp atımı sayma görevi sırasında fonksiyonel yakın kızılötesi spektroskopi (fNIRS) ile ölçülen kortikal oksihemoglobin (HbO) yanıtlarını araştırmaktır. Çalışma, interoseptif süreçlerin bilinç mekanizmalarıyla ilişkisini anlamaya ve davranışsal ölçütlerden bağımsız biyobelirteçlerin geliştirilmesine katkı sağlamak üzere bir pilot çalışma olmayı hedeflemiştir.
Gereç ve Yöntem: Çalışmaya yaş, cinsiyet ve eğitim açısından benzeştirilmiş 13 sağlıklı birey ve 6 bilinç bozukluğu bulunan hasta dahil edilmiştir. fNIRS ölçümleri 35 kanallı NIRScout cihazı ile frontal ve parietotemporal bölgelerden alınmıştır. Dinlenim koşulunda 7 dakikalık gözler kapalı kayıt yapılmış, interoseptif görev olarak Schandry'nin kalp atımı sayma paradigması uygulanmıştır. ΔHbO yanıtları Homer3 yazılımında işlenmiş, parametrik olmayan testlerle analiz edilmiştir.
Bulgular: Dinlenim durumunda gruplar arasında anlamlı fark bulunmamıştır. Sağlıklı bireylerde kalp atımı sayma görevi sırasında sol frontal ve mid frontal bölgelerde ΔHbO düzeylerinde anlamlı azalma gözlenmiştir. Bilinç bozukluğu grubunda dinlenim ve görev koşulları arasında fark saptanmamıştır. Gruplar arası karşılaştırmalarda, sağlıklı bireylerin sol ve sağ temporoparietal bölgelerde daha düşük ΔHbO değerlerine sahip olduğu belirlenmiştir.
Sonuç: Çalışma, interoseptif görevler sırasında sağlıklı bireylerde frontal ve temporoparietal bölgelerde anlamlı hemodinamik değişiklikler görüldüğünü; bilinç bozukluğu olan bireylerde ise görevle ilişkili yanıtların belirginleşmediğini göstermiştir. Temporoparietal bölgelerdeki farklılıklar, bu alanların interoseptif farkındalık ve bilinçli deneyimle ilişkisini desteklemektedir. Bulgular, sınırlı örneklem büyüklüğüne rağmen fNIRS'in bilinç bozukluklarında biyobelirteç geliştirilmesine katkı sağlayabilecek bir yöntem olduğunu düşündürmektedir.
Anahtar Kelimeler: İnterosepsiyon, Hemodinamikler, Fonksiyonel Yakın Kızılötesi Spektroskopisi, Bilinç Bozuklukları

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INTRODUCTION

Interoception is defined as the perception and interpretation of internal physiological signals arising from cardiac, respiratory, and gastrointestinal processes (1,2). This process not only maintains homeostatic balance but also contributes to the formation of subjective experience, the sense of self, and emotional processing (3). The insula, anterior cingulate cortex, and prefrontal regions stand out as central structures in the cortical representation of interoceptive information (4).

Vegetative state (VS) and minimally conscious state (MCS), which are part of the spectrum of disorders of consciousness, differ in terms of levels of awareness. Although behavioral scales used in clinical practice (e.g., Coma Recovery Scale-Revised) are valuable for diagnosis, they may lead to misclassification due to limited or absent motor responses (5,6). Therefore, the investigation of interoceptive processes is of critical importance for the development of biomarkers independent of behavioral measures in the assessment of the level of consciousness (7,8).

Studies conducted in healthy individuals have shown activations in the insula, medial prefrontal cortex, and parietal regions during heartbeat awareness or respiratory tasks (9–11). These regions have also been associated with the default mode network (DMN) and attention networks. The findings indicate that interoception is related not only to bodily awareness but also to the holistic structure of conscious experience.

Functional near-infrared spectroscopy (fNIRS) is a portable and non-invasive neuroimaging method that provides indirect information about neuronal activity by measuring cortical oxyhemoglobin (HbO) changes (12). Compared to functional magnetic resonance imaging (fMRI), fNIRS does not require strict movement restriction; and compared to electroencephalography (EEG), it provides more direct information about regional oxygenation, making it particularly valuable for bedside assessments (13,14). These features make fNIRS a valuable tool for evaluating patients with disorders of consciousness.

Previous studies have used fNIRS to assess interoceptive tasks in healthy subjects and cognitive paradigms in patients with disorders of consciousness. One such study demonstrated increased frontal connectivity during a heartbeat counting task (HCT) in healthy individuals (15). Another study showed a decrease in HbO levels in the prefrontal cortex during interoception tasks (16). In their 2017 study, Abdalmalak et al. reported that patients in a minimally conscious state exhibited response patterns during motor imagery tasks that were similar to those observed in healthy controls (17). In another study, they discussed whether the fNIRS method could be used to detect disorders of consciousness (18).

The application of fNIRS during interoception tasks in both healthy individuals and patients with disorders of consciousness remains limited, and current findings are inconclusive. While evidence exists regarding the cortical representation of interoceptive processes in healthy individuals, a significant knowledge gap persists in patient populations. This pilot study, therefore, aims to compare cortical HbO responses measured with fNIRS during resting state and a heartbeat counting task in healthy individuals and patients with disorders of consciousness, with the dual objective of providing preliminary insights into the mechanisms of consciousness and establishing a foundation for the development of novel clinical assessment strategies.

MATERIALS AND METHODS

The study was conducted at the Clinical Electrophysiology, Neuroimaging and Neuromodulation Laboratory of the Health Sciences and Technologies Research Institute (SABITA), Istanbul Medipol University, and in the intensive care units and neurology wards of Bağcılar Medipol Mega University Hospital. The inclusion criteria for healthy individuals were being 18 years or older, right-handed, having no history of neurological or psychiatric disorders, not using medication, having no cognitive impairment (MoCA $\geq$ 23), and being a native Turkish speaker. For individuals with disorders of consciousness, the inclusion criteria were being 18 years or older, right-handed, having wakefulness but no awareness or only limited awareness, stable medical condition, no use of sedative/hypnotic medication within the last 24 hours, and being a native Turkish speaker. Exclusion criteria were pregnancy and hearing impairment for healthy participants; and for patients with disorders of consciousness, a known history of neurological and/or psychiatric disorders, uncontrolled epileptic seizures, severe organ failure, increased intracranial pressure, unstable vital signs, sepsis, cancer, known hearing impairment, brain death, and deep coma. Data were obtained through a demographic information form, neuropsychological assessment, evaluation of consciousness level, and hemodynamic measurements. The Montreal Cognitive Assessment (MoCA) was applied to healthy participants, while the JFK Coma Recovery Scale-Revised (CRS-R) was administered by a neurologist to individuals with disorders of consciousness (5,19). Hemodynamic measurements were performed using functional near-infrared spectroscopy.

fNIRS data were recorded using the NIRStar Acquisition software (v15.3, NIRx Medizintechnik GmbH, Germany) with a multi-channel, continuous-wave device (NIRScout, Medical Technologies LLC, Berlin, Germany). A total of 35 channels were placed over the frontal and parietotemporal regions in accordance with the EEG 10–20 system. The distance between optodes was adjusted not to exceed 3 cm. Recordings were obtained at a sampling rate of 4.17 Hz, with wavelengths of 760 nm and 850 nm. Details of channel placement and anatomical locations are presented in Figure 1 and Table 1.

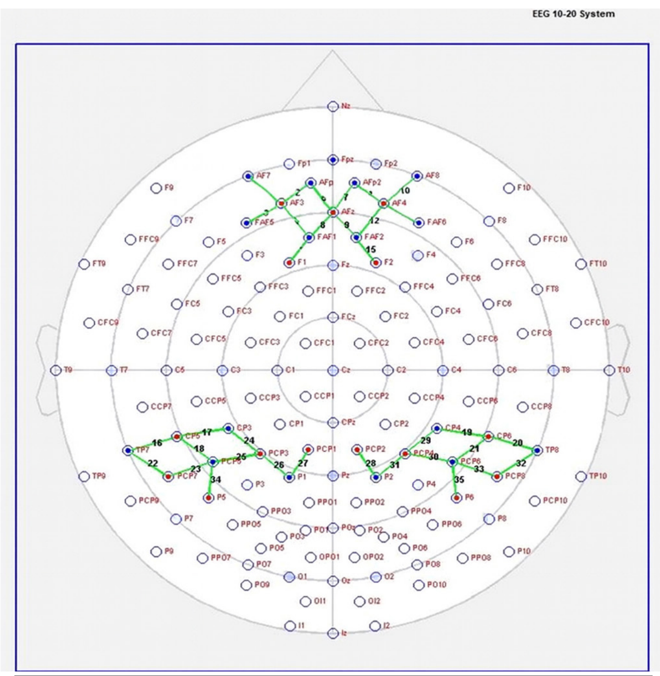

Figure 1. Optode placement based on the international 10–20 system. Red circles represent source optodes and blue circles represent detector optodes. Green lines indicate measurement channels formed between source–detector pairs

During the resting-state recordings, participants were asked to remain awake with their eyes closed for 7 minutes. The interoception task was assessed using the heartbeat counting task (HCT), based on Schandry's paradigm and the adaptation by Desmedt et al. (20,21). Participants were instructed to silently count their own heartbeats during intervals of 25, 35, and 45 seconds, without physically checking their pulse. The beginning and end of each interval were signaled by verbal instructions generated through the E-Prime paradigm, which also inserted event markers into the data for subsequent analysis. fNIRS recordings were obtained from all channels during this period.

Preprocessing of the data was performed using Homer3 software (v1.80.2). Motion artifacts were corrected using wavelet-based methods, followed by the application of a band-pass filter with a frequency range of 0.01–0.08 Hz. Optical density values were converted into concentrations using the modified Beer–Lambert law, and block averages were calculated to obtain HbO responses. (22).

Channels were analyzed in regional clusters: left frontal (Channels 1, 2, 3, 4, 14), right frontal (Channels 10, 11, 12, 13, 15), midfrontal (Channels 5, 6, 7, 8, 9), left temporoparietal (Channels 16, 17, 18, 22, 23, 25, 34), right temporoparietal (Channels 19, 20, 21, 30, 32, 33, 35) and midparietal (Channels 24, 26, 27, 28, 29, 31). Statistical analyses were performed using IBM SPSS 20.0 and JASP 0.19.3 software, with descriptive statistics reported as mean and standard deviation. Since the number of participants was below 30, non-parametric tests were preferred; the Mann-Whitney U test was used for between-group comparisons, and the Wilcoxon Signed-Rank Test for within-group comparisons. Statistical significance was defined as $p < 0.05$.

RESULTS

Thirteen healthy participants and six participants with disorders of consciousness were included in the study. The groups did not differ in terms of age, sex, or years of education ($p > 0.05$). Demographic information of the participants is presented in Table 2. Hemodynamic recordings obtained from both groups during the resting state and interoception task were analyzed according to the parameters described in the Materials and Methods section. Oxyhemoglobin change (ΔHbO) values were examined for regional clusters. Results of the Mann-Whitney U test during the resting state showed no significant differences between groups.

Table 1. Channel Information According to LPBA40 Atlas			
Channel	**Optode Number**	**Optode Location**	**Corresponding Regions**
Channel 1	1-1	AF3-AF7	Left middle frontal gyrus - Left middle frontal gyrus & lateral orbitofrontal gyrus
Channel 2	1-4	AF3-AFp1	Left middle frontal gyrus - Left superior & middle frontal gyrus
Channel 3	1-6	AF3-FAF5	Left middle frontal gyrus - Left inferior & middle frontal gyrus
Channel 4	1-7	AF3-FAF1	Left middle frontal gyrus - Left middle frontal gyrus
Channel 5	2-2	AFz-FPz	Left & right superior frontal gyrus - Right & left superior & middle frontal gyrus
Channel 6	2-4	AFz-AFp1	Left & right superior frontal gyrus - Left superior & middle frontal gyrus
Channel 7	2-5	AFz-AFp2	Left & right superior frontal gyrus - Right superior & middle frontal gyrus
Channel 8	2-7	AFz-FAF1	Left & right superior frontal gyrus - Left superior & middle frontal gyrus
Channel 9	2-8	AFz-FAF2	Left & right superior frontal gyrus - Right superior & middle frontal gyrus
Channel 10	3-3	AF4-AF8	Right middle frontal gyrus - Right inferior frontal gyrus & lateral orbitofrontal gyrus
Channel 11	3-5	AF4-AFp2	Right middle frontal gyrus - Right superior & middle frontal gyrus
Channel 12	3-8	AF4-FAF2	Right middle frontal gyrus - Right middle frontal gyrus
Channel 13	3-9	AF4-FAF6	Right middle frontal gyrus - Right inferior & middle frontal gyrus
Channel 14	4-7	F1-FAF1	Left superior & middle frontal gyrus - Left middle frontal gyrus
Channel 15	5-8	F2-FAF2	Right superior & middle frontal gyrus - Right middle frontal gyrus
Channel 16	6-10	CP5-TP7	Left supramarginal gyrus - Left middle temporal gyrus
Channel 17	6-11	CP5-CP3	Left supramarginal gyrus - Left inferior parietal lobule
Channel 18	6-14	CP5-PCP5	Left supramarginal gyrus - Left angular gyrus
Channel 19	7-12	CP6-CP4	Right supramarginal gyrus - Right inferior parietal lobule
Channel 20	7-13	CP6-TP8	Right supramarginal gyrus - Right middle temporal gyrus
Channel 21	7-15	CP6-PCP6	Right supramarginal gyrus - Right angular gyrus
Channel 22	8-10	PCP7-TP7	Left inferior & middle temporal gyrus - Left middle temporal gyrus
Channel 23	8-14	PCP7-PCP5	Left inferior & middle temporal gyrus - Left angular gyrus
Channel 24	9-11	PCP3-CP3	Left angular gyrus & superior parietal gyrus - Left inferior parietal lobule
Channel 25	9-14	PCP3-PCP5	Left angular gyrus & superior parietal gyrus - Left angular gyrus
Channel 26	9-16	PCP3-P1	Left angular gyrus & superior parietal gyrus - Left superior parietal gyrus
Channel 27	10-16	PCP1-P1	Left superior parietal gyrus - Left superior parietal gyrus
Channel 28	11-17	PCP2-P2	Right superior parietal gyrus - Right superior parietal gyrus
Channel 29	12-12	PCP4-CP4	Right angular gyrus & superior parietal gyrus - Right inferior parietal lobule
Channel 30	12-15	PCP4-PCP6	Right angular gyrus & superior parietal gyrus - Right angular gyrus
Channel 31	12-17	PCP4-P2	Right angular gyrus & superior parietal gyrus - Right superior parietal gyrus
Channel 32	13-13	PCP8-TP8	Right inferior & middle temporal gyrus - Right middle temporal gyrus
Channel 33	13-15	PCP8-PCP6	Right inferior & middle temporal gyrus - Right angular gyrus
Channel 34	14-14	P5-PCP5	Left angular gyrus & middle occipital gyrus - Left angular gyrus
Channel 35	15-15	P6-PCP6	Right angular gyrus & middle occipital gyrus - Right angular gyrus

Table 2. Demographic Characteristics of Participants			
Variable	**Healthy Group (n = 13, M ± SD)**	**DoC Group (n = 6, M ± SD)**	**p**
Age	38,84±17,76	54,66±9,97	0,059
Gender	7F/6M	3F/3M	0,893
Years of Education	16,5±4,53	13,33±4,13	0,154

DoC = Disorders of Consciousness; M = Mean; SD = Standard Deviation; F = Female; M = Male

In healthy participants, comparison of the interoception (HCT) task and resting state revealed significant decreases in ΔHbO levels in the left frontal (p= 0.039) and mid frontal (p= 0.016) regions. No significant differences were found in the right frontal, left temporoparietal, right temporoparietal, or mid parietal regions. Regional ΔHbO statistics for healthy participants are presented in detail in Table 3 and illustrated in Figure 1.

In participants with disorders of consciousness, comparison of the interoception task and resting state showed no significant differences in ΔHbO across any region (p> 0.05). Results for this group across all regions are provided in Table 4, with regional distributions illustrated in Figure 2.

When healthy and disorders of consciousness groups were compared during the HCT using the Mann–Whitney U test, results indicated that ΔHbO levels in the left temporoparietal (p= 0.036) and right temporoparietal (p= 0.022) regions were lower in the healthy group compared to the disorders of consciousness group. In the midfrontal region, a trend toward significance was observed (p= 0.072). No significant differences were found in other regions. Detailed between-group comparison results are shown in Table 5, and mean regional ΔHbO values are illustrated in Figure 3.

Table 3. Comparison of Hemoglobin Oxygenation (ΔHbO) Changes by Region During Rest and Heartbeat Counting Task in Healthy Participants. Wilcoxon Signed-Rank Test (n = 13)

Region	Condition (Rest – HCT)	Mean Rank	Sum of Ranks	Z	p
Left Frontal	Negative Ranks	5.33	16.00	-2.062	**0.039***
	Positive Ranks	7.50	75.00		
	Ties				
Right Frontal	Negative Ranks	6.00	24.00	-1.503	0.133
	Positive Ranks	7.44	67.00		
	Ties				
Mid Frontal	Negative Ranks	3.67	1.00	-2.411	**0.016***
	Positive Ranks	8.00	80.00		
	Ties				
Left TP	Negative Ranks	4.33	26.00	-1.363	0.173
	Positive Ranks	9.29	65.00		
	Ties				
Right TP	Negative Ranks			-1.642	0.101
	Positive Ranks	7.33	22.00		
	Ties	6.90	69.00		
Mid Parietal	Negative Ranks	8.00	32.00	-.943	0.345
	Positive Ranks	6.56	59.00		
	Ties				

*ΔHbO = Change in oxyhemoglobin concentration; Left TP = Left temporoparietal; Right TP = Right temporoparietal; *p < 0.05*

Table 4. Comparison of Oxygenated Hemoglobin Concentration Changes During Rest and HCT Interoceptive Task in Participants with DoC. Wilcoxon Signed-Rank Test (n = 6)

Region	Condition (Rest - HCT)	Mean Rank	Sum of Ranks	Z	p (Asymp. Sig. 2-tailed)
ΔHbO Left Frontal	Negative Ranks	4.00	4.00	-1.363	0.173
	Positive Ranks	3.40	17.00		
ΔHbO Right Frontal	Negative Ranks	2.00	2.00	-1.782	0.075
	Positive Ranks	3.80	19.00		
ΔHbO Mid Frontal	Negative Ranks	3.00	3.00	-1.572	0.116
	Positive Ranks	3.60	18.00		
ΔHbO Left TP	Negative Ranks	3.50	7.00	-0.734	0.463
	Positive Ranks	3.50	14.00		
ΔHbO Right TP	Positive Ranks	3.00	9.00	-0.314	0.753
	Equal Ranks	4.00	12.00		
ΔHbO Mid Parietal	Negative Ranks	3.50	14.00	-0.734	0.463
	Positive Ranks	3.50	7.00		

*ΔHbO = Change in oxygenated hemoglobin; Left TP = Left temporoparietal; Right TP = Right temporoparietal; *p < 0.05*

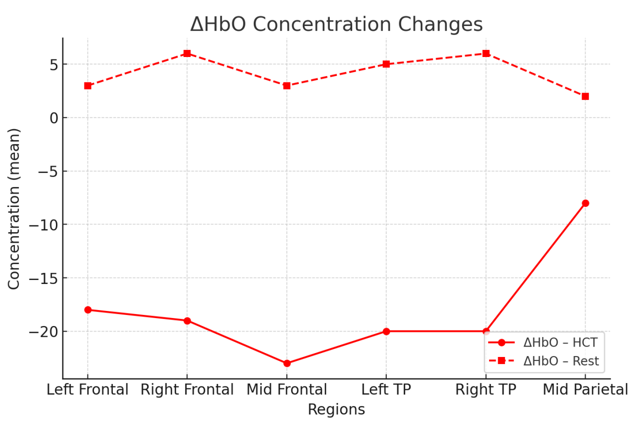

Figure 2. Distribution of mean ΔHbO values across cortical localizations during the resting state and heartbeat counting task in healthy participants

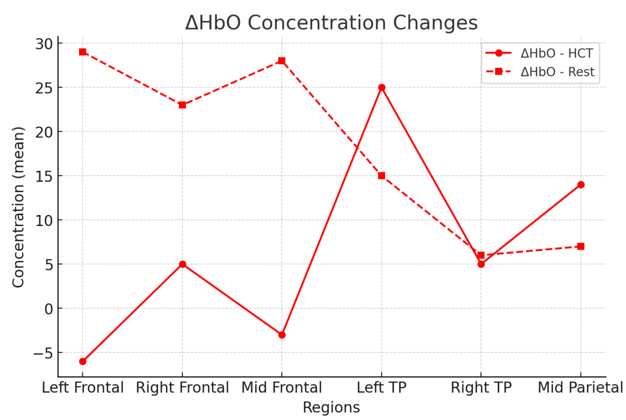

Figure 3. Distribution of mean ΔHbO values across cortical localizations during the resting state and heartbeat counting task in participants with DoC

Table 5. Comparison of Oxygenated Hemoglobin Concentration Changes Across Groups During the HCT Interoceptive Task. Mann-Whitney U Test (N = 19)

Region	Group	N	Mean Rank	Sum of Ranks	U	p
ΔHbO Left Frontal	Healthy	13	8.923	116.000	25.000	0.244
	DOC	6	12.333	74.000		
ΔHbO Right Frontal	Healthy	13	8.846	115.000	24.000	0.210
	DOC	6	12.500	75.000		
ΔHbO Mid Frontal	Healthy	13	8.385	109.000	18.000	0.072
	DOC	6	13.500	81.000		
ΔHbO Left TP	Healthy	13	8.154	106.000	15.000	**0.036***
	DOC	6	14.000	84.000		
ΔHbO Right TP	Healthy	13	8.000	104.000	13.000	**0.022***
	DOC	6	14.333	86.000		
ΔHbO Mid Parietal	Healthy	13	9.692	126.000	35.000	0.765
	DOC	6	10.667	64.000		

*ΔHbO = Change in oxygenated hemoglobin; Left TP = Left temporoparietal; Right TP = Right temporoparietal; *p < .05*

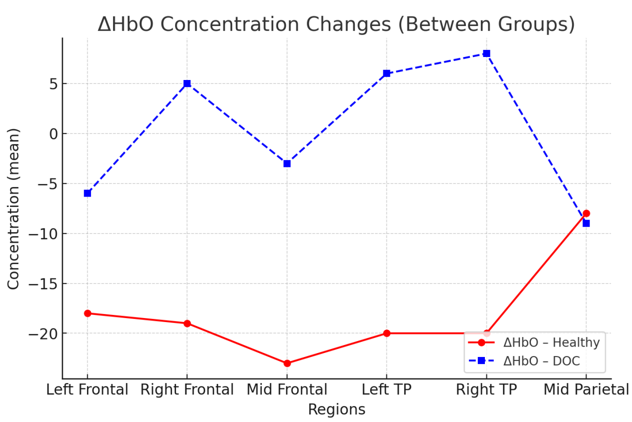

Figure 4. Comparison of mean ΔHbO values across cortical localizations between healthy and DoC groups during the heartbeat counting task

DISCUSSION

In interoceptive awareness tasks, particularly paradigms that require focusing on internal bodily signals, such as heartbeat counting, the analysis of cortical hemodynamic responses is important for evaluating the relationship between interoception and conscious awareness. Data obtained with fNIRS have the potential to provide insights into the neuroanatomical foundations of interoceptive awareness by examining oxygenation changes, particularly in frontal and parietal regions. In healthy participants, ΔHbO levels in the left frontal and midfrontal regions were observed to decrease significantly during the HCT compared to the resting state. Although other studies in the literature have reported increased oxygenation in frontal areas (15), this finding is consistent with previous research suggesting that prefrontal regions may show reduced oxygenation responses when task demands for internal attention and awareness increase (16).

Among participants with disorders of consciousness, ΔHbO responses did not differ significantly between resting and task conditions. This finding may suggest that task-related cortical oxygenation responses were either too weak or that sufficient cortical changes could not be triggered due to inadequate processing of task instructions. Previous studies have shown that the integrity of interoceptive networks, particularly the anterior insula and medial prefrontal cortex, plays a decisive role in tasks such as heartbeat awareness (25,26).

In this study, the absence of a significant difference in ΔHbO between resting and task conditions in participants with disorders of consciousness suggests that task-related cortical oxygenation responses remained weak. In the EEG literature, heartbeat-evoked responses/potentials (HER/HEP) measurements have been shown to differentiate levels of consciousness under certain conditions; for example, in emerged-MCS (eMCS) patients, the peak power (global field power) and complexity measures of HEP are higher compared to prolonged DoC (27). In addition, HER markers extracted from resting EEG have been able to classify the distinction between UWS and MCS with high accuracy, and these HER-based scores have been shown to correlate with glucose metabolism in DMN nodes as measured by fluorodeoxyglucose positron emission tomography (28). More recent multidimensional assessments have also shown that HER variance and frontal segregation increase with the presence of consciousness (29). In contrast, the fNIRS findings of the present study did not reveal a ΔHbO differentiation between resting and task conditions in the DoC group; this may indicate that the modulations observable at the electrophysiological level (EEG/HER) could not be captured by fNIRS due to limitations of the hemodynamic window and/or task processability.

A noteworthy finding of our study is that, while no significant differences were observed between groups during the resting state, differences emerged particularly in the temporoparietal regions during the interoceptive task. According to the between-group comparison results, during the HCT, healthy participants showed significantly lower ΔHbO values in the left and right temporoparietal regions compared to the disorder of consciousness groupIn the literature, it is generally accepted that, according to classical neurovascular coupling, increases in neural activity are accompanied by an increase in oxyhemoglobin concentration and a decrease in deoxyhemoglobin levels in the corresponding regions (14). Therefore, during interoceptive tasks such as heartbeat counting, an increase in HbO is expected, particularly in the insula, prefrontal, anterior cingulate, and parietal regions. However, the lower oxygenation levels observed in these regions among healthy individuals may reflect more efficient neural processing in response to the interoceptive stimulus, or DMN deactivation during focused attention on the stimulus. This finding is consistent with previous studies highlighting the role of the right temporoparietal region in self-representation and internal attention processes (1,25). The temporoparietal regions are also known to play an important role in interoceptive self-related processes, particularly in functions such as heartbeat perception, body awareness, and the sensory integration related to self (3,30,31). Studies conducted in recent years have shown that not only the insula and anterior cingulate cortex, but also the temporoparietal regions are involved in cardiac-based interoceptive tasks (32–34). Temporoparietal regions have emerged as a key component of the neural circuitry that supports not only external social perception but also the internal monitoring of bodily signals. Anatomically, the temporoparietal junction (TPJ) lies at the intersection of the temporal and parietal lobes and is known to mediate high-level social cognitive tasks such as empathy and theory of mind (35,36). In addition, the inferior parietal cortex and supramarginal gyrus, which are part of the broader temporoparietal complex, contribute to multisensory integration and the coding of peripersonal space—a process essential for distinguishing self from others (37). Critchley et al. (2004) reported that the inferior parietal lobule was activated together with the insula during heartbeat perception. Studies conducted on developmental samples have also supported these findings (38), and Klabunde et al. (2019) demonstrated that the inferior parietal lobule was activated together with the insula and prefrontal regions during a heartbeat detection task in children and adolescents (34). In addition, a meta-analysis conducted by Schulz et al. (2016) revealed the relationship between heart-focused interoceptive accuracy and sensitivity measures and the inferior parietal lobule, highlighting the importance of this region (39). At the theoretical level, Park and Blanke (2019) and Salvato et al. (2020) stated that the temporoparietal region plays a central role in the integration of internal and external bodily signals, serving as a critical hub in self-representation and body awareness processes (25,40). More recent findings also show that interoceptive performance is associated with individual differences and that oxygenation responses can reflect these variations (32). In this context, the ΔHbO differentiation observed in the temporoparietal regions of the healthy group in our study can be considered consistent with the literature reporting parietal contributions during interoceptive tasks. Moreover, the group differences that emerged may not reflect a more functional awareness or better perfusion response in patients with disorders of consciousness, but rather neural inefficiency, lack of control, or a compensatory hemodynamic reaction (41).

The findings of this study demonstrate that interoceptive processes extend beyond the insula and prefrontal regions, with the temporoparietal areas also playing a critical role within this network. In healthy individuals, the decrease in oxygenation observed in the frontal regions during the task suggests a reorganization of attentional networks and deactivation of the default mode network, while the differentiations in the temporoparietal regions highlight the close link between self-representation, body awareness, and interoceptive experience. In contrast, the absence of significant task-related responses in individuals with disorders of consciousness may indicate that disruptions in the integrity of these neural networks are related to the loss of interoceptive awareness.

CONCLUSION

This study represents a pilot attempt to examine cortical oxygenation responses during rest and heartbeat counting tasks in healthy individuals and those with disorders of consciousness. The findings revealed that interoceptive tasks induced significant changes in the frontal and temporoparietal regions of healthy participants, whereas no clear differences were observed between rest and task conditions in patients. The group differences identified in the temporoparietal regions further support the involvement of these areas in interoceptive awareness and the formation of conscious experience. However, the limited sample size and clinical heterogeneity restrict the generalizability of the results. Future studies with larger cohorts and multimodal approaches are needed to provide stronger evidence for the potential use of interoception as a diagnostic and prognostic biomarker in disorders of consciousness.

DECLARATIONS

Conflict of Interest

The author declares that there is no conflict of interest within the scope of this study.

Ethical Approval

This study was approved by the Non-Interventional Clinical Research Ethics Committee of Istanbul Medipol University on 29/12/2021 with the decision number E-10840098-772.02-6727.

Informed Consent

Written informed consent was obtained from healthy participants prior to participation. For individuals with disorders of consciousness, written informed consent was obtained from their legal guardians.

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