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Subjective Health Perception Moderates the Antidepressant Effects of Home-Based Transcranial Direct Current Stimulation in Perinatal Women: A Real-World Observational Study

Sra Jung[1*], Hyejin Won[1*], Soojin Back[1], Hyun-Ju Kim[2], Jae-Seob Park[3], Hee Young Cho[4,5] ✉, and Min-Kyoung Kim[1] ✉

[1]Department of Psychiatry, CHA Ilsan Medical Center, CHA University School of Medicine, Goyang, Republic of Korea
[2]Department of Psychiatry, CHA Bundang Medical Center, CHA University School of Medicine, Seongnam, Republic of Korea
[3]Department of Psychiatry, Yongin Severance Hospital, Yonsei University College of Medicine, Yongin, Republic of Korea
[4]Department of Obstetrics and Gynecology, Seoul National University Hospital, Seoul National University College of Medicine, Seoul, Republic of Korea
[5]Institute of Reproductive Medicine and Population, Medical Research Center, Seoul National University, Seoul, Republic of Korea

Objective Perinatal depression often remains undertreated due to concerns about antidepressant exposure during fertility treatment, pregnancy, or breastfeeding. Non-pharmacological, home-based interventions such as transcranial direct current stimulation (tDCS) present a promising alternative; however, real-world evidence in perinatal populations remains limited.

Methods This prospective observational study included 38 women who received infertility, pregnancy, or postpartum treatment at four hospitals in South Korea. Participants self-administered anodal tDCS targeting the left dorsolateral prefrontal cortex for 20–28 sessions over 4 weeks. Depressive symptoms were assessed using the Center for Epidemiologic Studies Depression Scale (CES-D) at baseline and weeks 2, 4, and 8. Subjective health perception was measured at baseline using a 5-point Likert scale.

Results Time had a significant effect on depressive symptoms (Wald χ^2=90.75, p<0.001), with the largest reduction observed during the first 2 weeks. The CES-D scores remained significantly lower than baseline at week 8, 4 weeks after treatment ended. Subjective health perception was significantly associated with baseline depression severity (Wald χ^2=26.41, p<0.001), and its interaction with time was also significant (Wald χ^2=320.18, p<0.001). Participants with poorer perceived health (scores 4–5) experienced greater depressive symptom reductions than those with more favorable perceptions (scores 1–2).

Conclusion Home-based tDCS was feasible and associated with clinically meaningful improvement in depressive symptoms among perinatal women. Those who initially perceived their health more negatively showed greater response, suggesting subjective health perception may serve as a useful moderator and potential marker to inform personalized treatment strategies.

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Keywords Perinatal depression; Transcranial direct current stimulation; Subjective health perception.

INTRODUCTION

Perinatal depression refers to depressive symptoms that emerge during infertility treatment, pregnancy, or the postpartum period, representing a prevalent and clinically relevant mental health issue. Globally, an estimated 20%–25% of women experience elevated depressive symptoms during the perinatal period, although prevalence rates vary depending on population characteristics, assessment tools, and healthcare access.[1,2] In South Korea, perinatal mood disturbances are common and frequently undertreated, particularly among women undergoing assisted reproductive treatment.[3,4] These depres-

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✉ **Correspondence:** Hee Young Cho, MD, PhD
Department of Obstetrics and Gynecology, Seoul National University College of Medicine, 101 Daehak-ro, Jongno-gu, Seoul 03080, Republic of Korea
Tel: +82-2-2072-4033, **Fax:** +82-2-2762-7251, **E-mail:** hycho.md@gmail.com

✉ **Correspondence:** Min-Kyoung Kim, MD, PhD
Department of Psychiatry, CHA Ilsan Medical Center, CHA University School of Medicine, 1205 Jungang-ro, Ilsandong-gu, Goyang 10414, Republic of Korea
Tel: +82-31-782-3157, **Fax:** +82-31-782-7567, **E-mail:** mkkim@chamc.co.kr

*These authors contributed equally to this work.

sive symptoms not only cause individual distress but are also associated with impairing in maternal functioning, strained partner relationships, and adverse effects on infant emotional and cognitive development.[5,6] Therefore, early identification and effective management of perinatal depression should be a public health priority.

Despite its high burden, pharmacologic treatment for perinatal depression is often underutilized due to concerns about fetal safety, teratogenic risk, and medication transfer through breast milk.[7,8] Women undergoing infertility treatment may avoid antidepressants due to concerns about treatment efficacy or reproductive outcomes,[9,10] while pregnant and postpartum women frequently experience anxiety about fetal development and neonatal medication exposure during lactation.[11] Consequently, many perinatal women remain undertreated during periods of heightened vulnerability. These barriers underscore the urgent need for safe, accessible, and nonpharmacological interventions that can be flexibly applied across the perinatal continuum. Among these strategies, neuromodulation techniques, such as transcranial direct current stimulation (tDCS), have gained attention for their favorable safety profile, portability, and potential antidepressant effects.[12-14]

tDCS is a non-invasive neuromodulation method that delivers low-intensity electrical currents to targeted brain regions. Clinical trials in general populations have demonstrated that tDCS can significantly reduce depressive symptoms, often within the first 1 to 2 weeks of treatment.[15] In particular, stimulation of the left dorsolateral prefrontal cortex (DLPFC), a region involved in cognitive control and emotion regulation, leads to mood improvement by modulating cortical excitability and frontolimbic network activity.[16] Open-label studies in pregnant women with depression have also reported reductions in depressive symptoms following repeated tDCS sessions without the pharmacokinetic or teratogenic risks associated with antidepressant use.[13,17] The portability and ease of use of home-based tDCS devices further support their real-world applicability, enabling flexible deployment across different stages of the perinatal period. These features suggest that tDCS may be a promising and scalable intervention to address current gaps in perinatal mental healthcare.

Despite growing evidence of the efficacy and feasibility of tDCS in alleviating depressive symptoms in perinatal populations,[13,17] little is known about individual factors that may influence treatment response. Subjective health perception, defined as an individual's overall evaluation of their health, has gained attention as a potential indicator of depressive symptom severity in various populations.[18,19] Studies suggest that negative subjective health perception is associated with heightened psychological distress, somatic symptom burden, and poor emotion regulation capacity.[20,21] Perinatal concerns about body changes, pregnancy outcomes, or maternal functioning may influence subjective health perceptions and emotional well-being.[22,23] Despite its subjective nature, perceived health status may reflect broader affective and cognitive vulnerabilities relevant to depression, providing a useful lens for understanding individual differences in treatment response.

Although the antidepressant effects of tDCS and the role of subjective health perceptions have been studied independently, their interaction in perinatal populations remains poorly understood. Given the limitations in pharmacological treatment options during pregnancy, postpartum, and infertility care, this study investigated whether baseline subjective health perception moderates the effect of home-based tDCS on depressive symptoms in perinatal women. We proposed the following hypotheses:

- Depressive symptoms would significantly decrease following a 4-week course of home-based tDCS, with effects sustained through week 8.
- Baseline subjective health perception would be associated with the overall severity of depressive symptoms.
- The trajectory of symptom changes over time would differ according to baseline subjective health perception.

METHODS

Participants

This open-label, real-world study enrolled women aged 19–50 years with mild to moderate major depressive disorder (MDD) during the perinatal period, defined as undergoing infertility treatment, currently pregnant, or within 2 months postpartum. Diagnosis was based on the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition criteria,[24] with severity confirmed by standardized cut-offs: Beck Depression Inventory-II scores of 18–28 or Montgomery–Åsberg Depression Rating Scale (MADRS) scores of 14–34. This prospective observational, multicenter study included 38 women between November 2023 and March 2025 from four academic hospitals in South Korea: Seoul National University Hospital, Ilsan CHA Hospital, Bundang CHA Hospital, and Yongin Severance Hospital, including 21 who were pregnant, 9 postpartum (within 2 months), and 8 undergoing infertility treatment. Eligible participants provided written informed consent and completed validated Korean-language assessments.

Exclusion criteria included diagnoses of bipolar disorder, psychotic depression, post-traumatic stress disorder, obsessive-compulsive disorder, high risk for suicide (MADRS item 10 score ≥5, recent suicide attempt within 6 months, or per clinical judgment), seizure history, contraindications for tDCS (e.g., metallic implants or medical devices, scalp conditions preventing electrode placement), severe uncontrolled illness,

recent participation in other clinical trials, or tDCS use within the past 6 months.

All study protocol was approved by the Institutional Review Board of CHA Ilsan Medical Center and conducted in accordance with the latest version of the Declaration of Helsinki and the principles of Good Clinical Practice (approval number: ICHA 2023-07-004). Written informed consent was obtained from all participants prior to their enrollment in the study.

Clinical assessments

Demographic and clinical characteristics were collected at baseline. Sociodemographic variables included age, educational level (categorized as high school graduate, college graduate, or master's degree or higher), marital status (married, divorced, or other), and current employment status. Job-related characteristics such as monthly household income were also recorded. Obstetric information included current reproductive status (undergoing fertility treatment, currently pregnant, or postpartum), number of offspring, whether the pregnancy was planned, method of conception (natural, intrauterine insemination, or in vitro fertilization), and number of fetuses (singleton or twin). Participants also reported their subjective perception of current health status using a single question ("How would you describe your current health status?") rated on a 5-point Likert scale (1=very healthy to 5=very unhealthy). This questionnaire was administered during the screening stage.

Depressive symptoms were assessed using the Korean version of the 20-item Center for Epidemiologic Studies Depression Scale (CES-D). This self-reported instrument evaluated the frequency of depressive symptoms over the past week using a 4-point Likert scale (0=rarely or none of the time to 3=most or all of the time). Total scores ranged from 0 to 60, with higher scores indicating more severe depressive symptoms. The CES-D was administered at four time points: baseline (V1), week 2 (V2), week 4 (V3), and week 8 (V4). All assessments were conducted by trained researchers across the four participating institutions, as illustrated in the study design flowchart (Figure 1).

tDCS intervention

Participants underwent a 4-week home-based tDCS protocol using the MINDD STIM+ (model YMS-201B+/201BS+; Ybrain Inc.), a third-grade medical device approved by the Korean Ministry of Food and Drug Safety (license no. 21-331) for home-based treatment of mild to moderate MDD. The device comprises a clinician-configured hospital docking station and portable stimulator for patient self-administration at home.

Following V1, the participants underwent a 4-week course of tDCS. Stimulation was delivered at an intensity of 2 mA for 30 minutes per session, once daily over 4 weeks, aiming for a total of 28 sessions. Participants were encouraged to complete stimulation at least five times per week, with 20 sessions as the minimum target. Saline-soaked sponge electrodes were applied via a headband, targeting the DLPFC with anodal stimulation over the left DLPFC (F3) and cathodal stimulation over the right DLPFC (F4), according to the international 10–20 electroencephalogram system. All stimulation parameters were preprogrammed at the clinic to ensure uniformity, and the device was set to the real stimulation mode. The sessions were performed independently at home, and adherence and safety were monitored using built-in sensors, remote tracking, and follow-up calls.

Statistical analysis

Descriptive statistics were used to analyze baseline characteristics. To evaluate the longitudinal effect of subjective health perception on CES-D score trajectories during the home-based tDCS treatment period, we applied Generalized Estimating Equations (GEE) with an identity link function and a normal distribution. GEE was selected for its robustness to non-normality and its capacity to handle missing data in repeated-measures designs. Independent variables included time (4 levels: V1–V4), baseline subjective health perception (5-point Likert

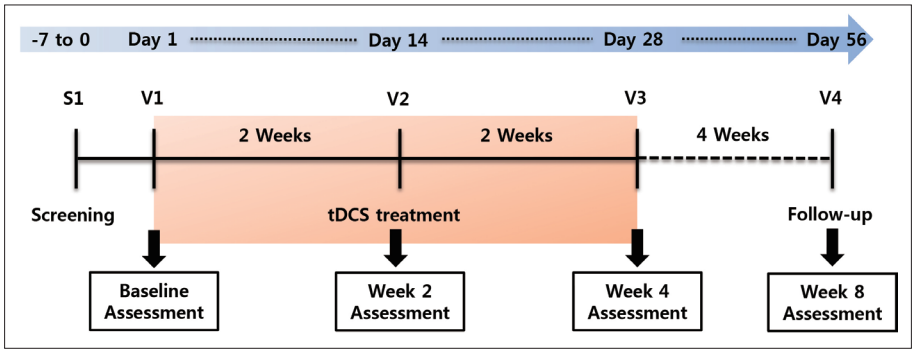

Figure 1. Study design flowchart. Flowchart illustrating the timeline of participant visits and clinical assessments. Participants underwent a 4-week home-based tDCS intervention beginning at visit 1 (V1), with depressive symptom evaluations conducted at baseline (V1), 2 weeks (V2), 4 weeks (V3), and 8 weeks (V4). tDCS, transcranial direct current stimulation.

Table 1. Demographic, employment characteristics and clinical characteristics of the study participants

Characteristic	Participants (N=38)/ Spouses (N=36)
Participant's age (yr)	36.7±9.4
Spouse's age (yr)	36.5±4.1
Categories	
Undergoing fertility treatment	8 (21.1)
Pregnant	21 (55.3)
Postpartum	9 (23.7)
Marital status	
Married	35 (92.1)
Divorced	1 (2.6)
Other	2 (5.3)
Education (participant)	
High school graduate	8 (21.1)
College graduate	26 (68.4)
Master's or higher	4 (10.5)
Education (spouse)	
High school graduate	7 (19.4)
College graduate	24 (66.7)
Master's or higher	5 (13.9)
Employment status (participant)	
Employed	23 (60.5)
Unemployed	15 (39.5)
Employment status (spouse)	
Employed	36 (100)
Unemployed	0 (0)
Monthly earned income (million won)	11.6±25.7
Number of offspring	
1	21 (32.3)
2	8 (21.6)
3	8 (21.6)
Planned pregnancy	
Yes	16 (76.2)
No	5 (23.8)
Method of conception	
Natural conception	13 (61.9)
Intrauterine insemination	3 (14.3)
In vitro fertilization	5 (23.8)
Number of fetuses	
Singleton	20 (95.2)
Twins	1 (4.8)
Subjective health perception	
1 (Very healthy)	4 (10.5)
2 (Somewhat healthy)	9 (23.7)
3 (Neutral)	7 (18.4)
4 (Somewhat unhealthy)	1 (0.03)
5 (Very unhealthy)	2 (0.05)
No response	15 (39.5)
CES-D score	
At V1	8.79±6.49
At V2	5.54±4.53
At V3	4.62±4.43
At V4	4.47±4.26

Data are presented as number (%) or mean±SD. CES-D, Center for Epidemiologic Studies Depression Scale; V1, baseline; V2, week 2; V3, week 4 (end of stimulation); V4, week 8 (follow-up).

scale, where 1=very healthy and 5=very unhealthy) and their interaction (time×subjective health perception). Participant ID was used as the subject variable, and an exchangeable working correlation matrix was specified to account for within-subject correlations across repeated measures. The reference category for time was set as V1, and the reference group for subjective health perception had the most favorable health ratings (score=1). Model fit was assessed using Quasi-likelihood under the Independence Model Criterion. Statistical significance was evaluated using Wald chi-square tests, with a p-value of <0.05 considered statistically significant. All analyses were performed using IBM SPSS Statistics for Windows, version 26.0 (IBM Corp.).

RESULTS

Demographic, employment, and clinical characteristics of the study participants

Baseline characteristics are summarized in Table 1. A total of 38 women treated at four academic hospitals in South Korea were enrolled in this study. The mean ages of participants and their spouses was 36.7±9.4 and 36.5±4.1 years, respectively. Most participants were married (92.1%) and had completed at least a college education (78.9%). Over half (60.5%) were currently employed as were all their spouses. Reproductive status included 21 pregnant women (55.3%), 9 postpartum (23.7%), and 8 undergoing fertility treatment (21.1%). Clinical and obstetric queries indicated that 76.2% of pregnancies were planned and 61.9% were conceived naturally. One participant was carrying twins. Participants' baseline subjective health perception varied: 10.5% rated themselves as "very healthy" (score=1), 23.7% as "somewhat healthy" (score=2), 18.4% as "neutral" (score=3), 2.6% as "somewhat unhealthy" (score=4), and 5.3% as "very unhealthy" (score=5), while 39.5% did not respond to this item. Mean CES-D scores decreased progressively over the study period: at baseline, 8.79±6.49 at baseline, 5.54±4.53 at week 2, 4.62±4.43 at week 4, and 4.47±4.26 at week 8.

Change in depressive symptoms over time

Figure 2 shows CES-D score trajectories across timepoints and health perception groups. Overall, CES-D scores decreased significantly over the 8-week period following tDCS treatment. The most marked reduction occurred between baseline (V1) and week 2 (V2), with continued improvement through week 4 (V3) and stabilization by week 8 (V4).

Influence of subjective health perception on depressive symptom severity trajectories

Table 2 presents GEE omnibus test results. The GEE model revealed a significant main effect of time (Wald χ^2=90.75, degrees of freedom [df]=3, p<0.001) and subjective health perception at baseline (Wald χ^2=26.41, df=4, p<0.001), as well as a significant time×health perception interaction (Wald χ^2=320.18, df=9, p<0.001). These findings indicate that the trajectory of depressive symptom change was moderated by participants' self-rated health status at baseline. Additional analyses confirmed the robustness of this effect. When reproductive stage (infertility, pregnant, postpartum) was added as a covariate, time (Wald χ^2=89.97, df=3, p<0.001) and the time×subjective health perception interaction (Wald χ^2=278.53, df=9, p<0.001) remained significant, whereas the time×reproductive stage interaction was not (Wald χ^2=8.65, df=6, p=0.195). When subjective health perception was dichotomized into good (scores 1–2) vs. not good (scores 3–5) with reproductive stage adjustment, the time×subjective health perception interaction also remained significant (Wald χ^2=17.49, df=3, p=0.001). Finally, treating nonresponders as a separate subjective health perception category yielded consistent findings (time×subjective health perception: Wald χ^2=21.42, df=6, p=0.002).

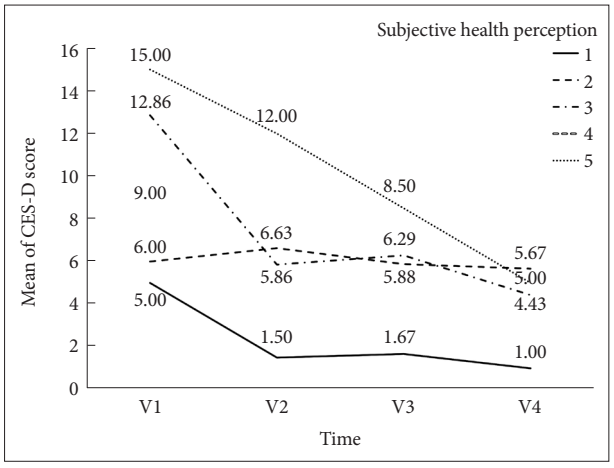

Figure 2. Changes of CES-D score by subjective health perception group over time. Line graph depicting the change in mean CES-D scores across four timepoints (V1, V2, V3, and V4), stratified by participants' baseline subjective health perception. CES-D, Center for Epidemiologic Studies Depression Scale; V1, visit 1; V2, 2 weeks visit; V3, 4 weeks visit; V4, 8 weeks visit.

As shown in Table 3 and Figure 2, participants who perceived their health as "very unhealthy" (Group 5) demonstrated the greatest reduction in CES-D scores (ΔCES-D=-10.00). Those reporting "neutral" (Group 3) health also showed substantial improvement (ΔCES-D=-8.43), while those who viewed themselves as "somewhat healthy" (Group 2) showed minimal change (ΔCES-D=-0.33). Supplementary Table 1 provides a detailed summary of the interaction effects and coefficient estimates from the GEE model.

Adherence and safety outcomes

Of the 38 participants, 21 completed at least 20 tDCS sessions over the 4-week period. Device adherence was remotely tracked using the built-in monitoring system of the MINDD STIM+unit. Adverse events were graded for severity (mild=no interference, moderate=intermittent discomfort or discontinuation, severe=requiring intervention). No serious events occurred. Tingling was most common (n=7; 18.4%), all mild. Itching (n=1; 2.6%) and transient headache (n=1; 2.6%) were mild and self-limited, while erythema in one participant (n=1; 2.6%) was moderate and led to discontinuation. Overall, home-based tDCS was well tolerated, with adverse events infrequent and mainly mild.

DISCUSSION

This study investigated the effectiveness of home-based

Table 2. Summary of GEE model results for CES-D scores

Effect	Wald χ^2	df	p
Time	90.75	3	<0.001
Subjective health perception	26.41	4	<0.001
Time×subjective health perception	320.18	9	<0.001

GEE, Generalized Estimating Equations; CES-D, Center for Epidemiologic Studies Depression Scale; Wald χ^2, Wald chi-square statistic; df, degrees of freedom.

Table 3. Change in CES-D scores by subjective health perception group

Subjective health perception	CES-D score at V1 (mean±SD)	CES-D score at V4 (mean±SD)	Mean change (ΔCES-D)	N
1 – Very healthy	5.00±1.41	1.00±1.73	-4.67±1.53	3
2	6.00±5.20	5.67±3.39	-0.33±3.39	9
3	12.86±4.22	4.43±4.58	-8.43±5.16	7
4	9.00± -	-	-	
5 – Very unhealthy	15.00±0.00	5.00±4.24	-10.00±4.24	2
Total	8.83±5.43	4.52±3.82	-4.57±5.47	21

CES-D, Center for Epidemiologic Studies Depression Scale; V1, baseline visit; V4, final follow-up visit at 8 weeks; ΔCES-D, change in CES-D score from baseline to week 8.

tDCS in perinatal women with mild to moderate depression and explored the influence of baseline subjective health perception. Depressive symptoms significantly decreased over the 8-week study period, with the most pronounced reduction occurring during the first 2 weeks of active treatment. Notably, the improvements were maintained at week 8, 4 weeks after the active treatment ended. A significant interaction between time and subjective health perception indicated that individuals who viewed their health more negatively experienced a greater symptom reduction. These results suggest that subjective health perception may serve as a clinically relevant moderator of tDCS treatment outcomes, potentially reflecting differences in emotional processing, or perceived health-related agency.

In the sample, the CES-D scores declined significantly over the 8-week period, with the most marked reduction occurring during the first 2 weeks of active tDCS treatment. Additional improvement was noted through week 4, and symptom reduction was maintained at week 8 and 4 after treatment cessation, indicating both rapid onset and sustained effects. These findings suggest that tDCS is a non-pharmacological option for managing depressive symptoms in perinatal women, a population often with limited options in the use of antidepressants because of concerns related to pregnancy, lactation, or reproductive health. Biologically, tDCS is believed to exert antidepressant effects by modulating cortical excitability and neuroplasticity, particularly through anodal stimulation of the left DLPFC,[25] a region involved in the top-down regulation of negative emotions and reward processing.[26,27] Mechanistic studies have suggested that tDCS influences glutamatergic and gamma-aminobutyric acid GABA-ergic neurotransmission, enhances brain-derived neurotrophic factor-dependent synaptic plasticity, and alters connectivity within the frontolimbic circuits associated with depression.[28,29] These neurophysiological effects provide a plausible basis for the antidepressant efficacy of tDCS. Clinical trials have consistently reported early onset symptom improvement with tDCS, often within the first 1 to 2 weeks of treatment.[30,31] Prior open-label studies in pregnant women with depression have demonstrated that repeated tDCS sessions could reduce depressive symptoms without the teratogenic or pharmacokinetic concerns linked to antidepressant medications.[13,32] Building on this evidence, our study demonstrated that a structured 4-week course of home-based tDCS led to rapid improvement with a durable effect lasting up to 4 weeks post-treatment. This sustained response highlights the therapeutic value of tDCS as a practical and scalable intervention in perinatal mental healthcare.

Beyond time effects, our findings demonstrated the role of subjective health perception as a potential moderator of treatment response. Participants who rated their general health poorly consistently reported higher CES-D scores, suggesting that self-perceived health status may have captured their underlying vulnerability to depression. One possible explanation is that negative perceptions of physical health may have reflected broader cognitive-affective schemas such as heightened health-related anxiety, increased somatization, or diminished interoceptive accuracy, all of which have been linked to depressive psychopathology.[33,34] Poor subjective health may have also coincided with more pronounced somatic symptoms such as sleep disturbances, low energy, or physical discomfort, which are frequently embedded in depressive symptom profiles.[18,35,36] In perinatal population, subjective health perception may also be influenced by hormonal fluctuations, altered body image, and concerns about maternal and fetal well-being, which could further intensify emotional distress.[37] Alternatively, viewing health pessimistically may have signaled a broader sense of reduced personal agency or resilience, which, in turn, contributed to feelings of helplessness and hopelessness, which are key features of depression.[38] Although subjective health ratings did not serve as objective clinical indicators, their consistent association with mood suggests that they may offer a modest value for screening and clinical risk stratification. Including a simple self-rated health item in perinatal mental health assessments may offer a pragmatic, low-burden approach for identifying individuals who could benefit from closer monitoring, even in the absence of overt medical illness.

Interestingly, participants who rated their health more negatively exhibited the greatest reduction in CES-D scores over the 8-week period. While this may have partly reflected regression to the mean or higher baseline severity, the magnitude and consistency of the effect suggest moderating role. Even after adjusting for baseline symptom levels, those with negative health perceptions showed greater treatment responsiveness. This indicated that subjective health beliefs may have captured more than symptom burden, reflecting cognitive-affective factors such as interoceptive sensitivity, somatic preoccupation, and health-related anxiety, all of which have been linked to depression and its neural substrates.[39,40] Individuals with poorer perceived health may have exhibited a stronger focus on internal bodily states processed via interoceptive networks such as the insula and anterior cingulate cortex.[41,42] Previous neuroimaging studies have shown that DLPFC-targeted tDCS alters activity in these regions,[43,44] potentially restoring the top-down regulation of somatic and emotional reactivity. Therefore, individuals with higher somatic sensitivity may be more responsive to prefrontal neuromodulation. In addition, poorer perceived health may coincide with heightened stress reactivity and dysregulated hypothalamic–pituitary–adrenal axis activity,[45,46] which are well-established biological pathways linking vulnerability to depression. Anodal tDCS of the

DLPFC has been shown to normalize fronto-limbic connectivity and modulate stress-related circuits, potentially restoring inhibitory control over amygdala and hypothalamic responses. From a psychological perspective, individuals who perceive themselves as less healthy may also hold stronger treatment expectancy and urgency for change, leading to greater engagement and adherence, which in turn enhances neuroplastic effects of neuromodulation. Moreover, heightened emotional salience or motivation to change may enhance therapeutic engagement. Prior research suggests that those with greater perceived vulnerability responded more strongly to interventions involving bodily awareness or self-care routines.[47] Thus, subjective health perception may reflect not only baseline symptom severity but also cognitive and emotional profiles that influence neuromodulatory treatment outcomes.

This study has several limitations. First, given the open-label design without a sham control, natural remission and placebo effects cannot be excluded. The findings should therefore be interpreted as associations rather than causal effects, and randomized controlled trials are warranted to confirm efficacy. Second, modest sample size and clinical heterogeneity across perinatal stages may have introduced variability, although it also enhances real-world clinical settings. Although the main analysis relied on the original five-level SHP scale with uneven cell sizes, additional dichotomized and nonresponse-inclusive analyses confirmed that the moderation effect was consistent. This robustness supports the validity of SHP as a meaningful marker despite sample size limitations in some categories. Third, subjective health perception was measured only once using a single-item scale; repeated assessments and the inclusion of objective health indicators would strengthen future analyses. Finally, depressive symptoms were assessed through self-reporting, without clinician-rated measures or biological markers, highlighting the need for multimodal evaluation in subsequent studies.

In conclusion, this study provides preliminary evidence supporting the feasibility, safety, and sustained antidepressant effects of home-based tDCS in treating depressive symptoms in perinatal women. The observed interaction with subjective health perception suggests that individual differences in self-appraised health may meaningfully shape responsiveness to treatment. Considering the limited pharmacological options available during the perinatal period, these findings highlight that tDCS is a promising, scalable, and non-stigmatizing therapeutic alternative. Incorporating subjective health assessments into clinical screening may also help identify individuals who will benefit the most from neuromodulatory interventions. Future larger-scale controlled studies are warranted to refine targeting strategies and optimize personalized treatment approaches in this vulnerable population.

Supplementary Materials

The Supplement is available with this article at https://doi.org/10.30773/pi.2025.0259.

Availability of Data and Material

The data necessary to interpret, replicate, and build upon the methods or findings reported in this article are available on request from the corresponding author, H.C. The data are not publicly available due to ethical restrictions that protect patient privacy and consent.

Conflicts of Interest

The authors have no potential conflicts of interest to disclose.

Author Contributions

Conceptualization: Sra Jung, Hyejin Won, Soojin Back, Hee Young Cho, Min-Kyoung Kim. Data curation: all authors. Formal analysis: Sra Jung, Hyejin Won, Soojin Back, Hee Young Cho, Min-Kyoung Kim. Supervision: Hee Young Cho, Min-Kyoung Kim. Validation: Hee Young Cho, Min-Kyoung Kim. Writing—original draft: Sra Jung, Hyejin Won. Writing—review & editing: Min-Kyoung Kim.

ORCID iDs

Sra Jung	https://orcid.org/0000-0001-5510-0680
Hyejin Won	https://orcid.org/0009-0003-4031-7491
Soojin Back	https://orcid.org/0009-0008-3534-7086
Hyun-Ju Kim	https://orcid.org/0000-0002-8093-3366
Jae-Seob Park	https://orcid.org/0000-0003-2597-2204
Hee Young Cho	https://orcid.org/0000-0001-7064-5056
Min-Kyoung Kim	https://orcid.org/0000-0002-5596-5665

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