Emotion Recognition Deficits in Psychiatric Disorders as a Target of Non-invasive Neuromodulation: A Systematic Review

Yuji Yamada¹, Takuma Inagawa¹, Naotsugu Hirabayashi¹, and Tomiki Sumiyoshi²

Abstract

Background. Social cognition deficits are a core feature of psychiatric disorders, such as schizophrenia and mood disorder, and deteriorate the functionality of patients. However, no definite strategy has been established to treat social cognition (e.g., emotion recognition) impairments in these illnesses. Here, we provide a systematic review of the literature regarding transcranial direct current stimulation (tDCS) and repetitive transcranial magnetic stimulation (rTMS) for the treatment of social cognition deficits in individuals with psychiatric disorders. Methods. A literature search was conducted on English articles identified by PubMed, PsycINFO, and Web of Science databases, according to the guidelines of the PRISMA statement. We defined the inclusion criteria as follows: (1) randomized controlled trials (RCTs), (2) targeting patients with psychiatric disorders (included in F20-F39 of the 10th revision of the International Statistical Classification of Diseases and Related Health Problems [ICD-10]), (3) evaluating the effect of tDCS or rTMS, (4) reporting at least one standardized social cognition test. Results. Five papers (3 articles on tDCS and 2 articles on rTMS) met the inclusion criteria which deal with schizophrenia or depression. The significant effects of tDCS or rTMS targeting the left dorsolateral prefrontal cortex on the emotion recognition domain were reported in patients with schizophrenia or depression. In addition, rTMS on the right inferior parietal lobe was shown to ameliorate social perception impairments of schizophrenia. Conclusions. tDCS and rTMS may enhance some domains of social cognition in patients with psychiatric disorders. Further research is warranted to identify optimal parameters to maximize the cognitive benefits of these neuromodulation methods.

Keywords
transcranial direct current stimulation (tDCS), repetitive transcranial magnetic stimulation (rTMS), social cognition, emotion recognition, RCT

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Introduction

Disturbances of cognitive function are a core feature of psychiatric disorders, such as schizophrenia and bipolar disorder, and deteriorate the functionality of patients.¹⁻² For example, several domains of neurocognitive function, such as learning memory, working memory, executive functioning, verbal fluency, and attention/information processing, are profoundly affected in schizophrenia.⁴ Similarly, social cognition,⁵ i.e., mental operations underlying social behavior, is impaired in schizophrenia. This aspect of the cognitive function represents a multidimensional construct that comprises emotion recognition, social perception, theory of mind (ToM), and attributional bias.⁶ Some studies report that social cognition explains the variance of functional outcome more effectively than does neurocognition.⁷⁻⁸ Developmental disorders, for example autism spectrum disorder (ASD),⁹ are also associated with social cognition deficits. The amelioration of deficits in social cognition may be considered secondary to the improvement of neurocognition.¹⁰ This is because neurocognitive dysfunction is a core symptom of psychotic disorders and is more strongly associated with social function than positive or negative symptoms.¹¹

¹Department of Psychiatry, National Center Hospital, National Center of Neurology and Psychiatry, Tokyo, Japan
²Department of Preventive Intervention, National Institute of Mental Health, National Center of Neurology and Psychiatry, Tokyo, Japan

Corresponding Author:
Tomiki Sumiyoshi, Department of Preventive Intervention for Psychiatric Disorders, National Institute of Mental Health, National Center of Neurology and Psychiatry, 4-1-1 Ogawahigashi-cho, Kodaira, Tokyo 187-8551, Japan. Email: sumiyot@ncnp.go.jp
Alternatively, the neural basis of social cognition and neurocognitive function may be partially independent. It is argued that improvement of social cognition directly leads to the rehabilitation of social function, whereas improvement of neurocognitive function affects the social function through the improvement of social cognition. In sum, it is legitimate to consider that the therapeutic intervention for improving social cognition may be mediated, at least in part, by alleviation of neurocognitive impairment.

To overcome social cognition impairments in psychiatric illnesses, psychosocial (eg, social cognition and interaction training) and pharmacological (eg, aripiprazole and risperidone) approaches have been attempted with limited effects. As an alternative approach, some types of neuromodulation, particularly non-invasive methods, have been drawing attention, including tDCS and rTMS. rTMS delivers repeated electromagnetic pulses to induce long-lasting modulation of neural activity, while tDCS applies a weak direct electrical current (eg, 1-2 mA) through two or more electrodes placed on the scalp to modulate cortical excitability. Both brain stimulation paradigms have been shown to be effective to treat depression and neurocognitive impairment of schizophrenia. Based on these observations, it would be worthwhile to evaluate the benefit of neuromodulation on social cognition in psychiatric disorders.

Here, we provide a systematic review of the literature on the treatment of social cognition deficits with tDCS or rTMS in individuals with psychiatric disorders.

Materials and methods

Inclusion criteria and search strategies

This systematic review was performed based on the PRISMA guidelines. We defined the inclusion criteria as follows: (1) RCTs, (2) targeting patients with psychiatric disorders (included in F20-F39 of ICD-10), (3) evaluating the effect of tDCS or rTMS, (4) reporting at least one standardized social cognition test, and (5) written in English. From inception to May 2, 2020, YY and TI independently conducted literature searches using the PubMed, PsycINFO, and Web of Science databases. The specific search terms used for these electronic databases are included in Supplemental Material 1. TS approved the final list of included studies.

Data extraction

The information for each study was independently extracted by YY and TI with discrepancies in coding resolved by TS.

Risk of bias in individual studies

According to the Cochrane Collaboration’s risk of bias tool, two independent reviewers (YY and TI) assessed (1) if patients were correctly randomized, (2) if the random allocation was properly concealed, and (3) if subjects and/or investigators and/or raters were blinded. We also assessed whether the authors collected and reported all pre-specified outcomes. A senior reviewer (TS) approved the final decision of the assessment of the risk of bias.

Results

The initial search provided a total of 374 records. After removing duplicates, 275 articles were screened, of which 25 English full texts were available. Five articles were found eligible for the systematic review. Articles describing studies that involved no sham group (n = 4), no psychiatric diagnosis (n = 9), and no social cognition outcome measures (n = 7) were excluded. The PRISMA study selection flowchart is shown in Figure 1. The summary of the risk of bias is presented in Supplemental Tables 1 and 2.

Systematic review

The 5 studies in the current review encompassed 3 tDCS articles (see Table 1) and 2 rTMS articles (see Table 2). There were considerable differences between the studies in terms of subjects' diagnosis, stimulation site, and outcome measures used. Among the 5 studies included in the review, 4 studies targeted schizophrenia subjects, while one study targeted depression. All tDCS studies applied anodal stimulation over the left dorsolateral prefrontal cortex (DLPFC), while one rTMS study sets the stimulation position to the left DLPFC and one rTMS study to the left inferior frontal gyrus (IFG) or right inferior parietal lobe (IPL).

Two tDCS studies employed a current intensity of 2 mA, while one used 1.5 mA. In addition, one study applied tDCS for 30 min, while the remaining ones applied stimulation for 20 min (n = 2). All tDCS studies except one used single-session designs, and all employed online-stimulation protocol (ie, outcome measures were assessed during active/placebo tDCS).

Outcome measures

Outcome measures identified through the specific search strategy in this study were discussed in relation to four domains of social cognition, ie, emotion recognition, social perception, ToM, and attributional bias (see Table 3).

Emotion recognition. The Mayer–Salovey–Caruso emotional intelligence test (MSCEIT) has 141 items and 8 ability subtests, which assess 4 components of emotional processing, ie, the ability to perceive, use, understand, and regulate emotions. On the other hand, the emotion identification test (EIT) and facial EIT (FEIT) are tests in which participants need to identify facial emotion based on photographs from the software. In the pictures of facial affect, participants need to answer the name of emotion shown on each face from a multiple-choice list of the six emotions (anger, disgust, happiness, sadness, surprise, and fear) based on 30 digital photographs of faces.
The empathic accuracy task (EAT)\textsuperscript{29} assesses whether participants judge positive or negative empathy by using 12 video clips (6 positive and 6 negative events). The emotion recognition task (ERT)\textsuperscript{30} used computer-generated video clips (using real actors) to assess the ability of participants to recognize specific emotions through facial expressions (anger, disgust, happiness, sadness, surprise, and fear).

Social perception. The profile of nonverbal sensitivity (PONS)\textsuperscript{31} is used to assess social perception, linked to social interaction, using scenes with facial expressions, voice intonations, and/or bodily gestures. The test of upper limb apraxia (TULIA)\textsuperscript{32} was used to assess the accuracy of performance of 48 hand gestures (meaningless, intransitive, or transitive), half of which are performed on demonstration of the experimenter (imitation), whereas the other half are performed following verbal instructions (pantomime).

ToM. The awareness of social inference test (TASIT)\textsuperscript{33} is 16 videotaped ToM tasks to understand the actors’ communicative intentions, by answering whether actors wanted to make participants believe the literal or non-literal meaning of their messages.

Effects of neuromodulation for social cognitive deficits

Effects of tDCS. Three studies included in the systematic review used tDCS. The characteristics of the included RCTs are shown in Table 1. Two studies included patients with schizophrenia, while one included depression. There were 3 patterns of tDCS montage in which the anode and the cathode were placed: (1) F3/Fp2, (2) F3/contralateral supraorbital area, and (3) Fp1/Fp2 of the international 10-20 electroencephalography system. Two studies used a 2 mA current intensity, while one used a 1.5 mA protocol. The duration of the intervention lasted from 20...
to 30 min, and 2 studies adopted single-session-online protocols. ToM (n = 2) and emotion recognition (n = 3) were the most frequently evaluated social cognition outcomes, while social perception was evaluated in one study, which used PONS. Among 3 tDCS studies, two of which found significant effects only in emotion recognition, one of which targeted depression\textsuperscript{25} and the other targeted schizophrenia\textsuperscript{22}, as shown in Table 1.

### Table 1. Characteristics of the Included tDCS Studies.

| Study           | Diagnosis    | Sample size (active/sham) | Montage (anode/cathode) | Intensity (mA) | Duration (min) | No. of sessions | Evaluation       | Outcomes                      | Results                      |
|-----------------|--------------|---------------------------|-------------------------|----------------|----------------|-----------------|-----------------|-------------------------------|------------------------------|
| Rassovsky et al\textsuperscript{21} | Schizophrenia | 37/37                     | F3/Fp2                  | 2              | 20             | 2               | Online          | MSCEIT, TASIT, EIT, EAT     | No significant effect        |
| Brennan et al\textsuperscript{25}  | Depression   | 17/17                     | F3/contralateral supraorbital area | 1.5            | 30             | 1               | Online          | ERT                           | Significant effects in emotion recognition |
| Rassovsky et al\textsuperscript{22} | Schizophrenia | 12/12                     | Fp1/Fp2                 | 2              | 20             | 1               | Online          | MSCEIT, TASIT, PONS, FEIT    | Significant effects in emotion recognition |

**Abbreviations:** MSCEIT, Mayer–Salovey–Caruso emotional intelligence test; TASIT, the awareness of social inference test; EIT, emotion identification test; EAT, empathic accuracy task; ERT, emotion recognition task; PONS, profile of nonverbal sensitivity; FEIT, facial emotion identification test.

Each study\textsuperscript{21,22,25} used the same parameters among active and sham groups. “Significant effects in emotion recognition” meant that stimulation enhanced the ability to identify facial emotion based on photographs or videos.\textsuperscript{22,25}

### Table 2. Characteristics of the Included rTMS Studies.\textsuperscript{a}

| Study          | Diagnosis | Sample size (active/sham) | Location (stimulation) | Frequency (Hz) | Intensity (%MT) | No. of stimuli (pulses) | Duration (days) | Evaluation | Outcomes | Results                          |
|----------------|-----------|---------------------------|------------------------|----------------|-----------------|------------------------|-----------------|------------|----------|----------------------------------|
| Walther et al\textsuperscript{23} | Schizophrenia | 20/20                    | Left IFG (iTBS)         | 30             | 80              | 600                    | 1               | Online    | TULIA               | No significant effect          |
|                |           |                           | Right IPL (cTBS)       | 30             | 100             | 801                    | 1               | Online    | TULIA               | Significant effects in social perception |
| Wölwer et al\textsuperscript{24}   | Schizophrenia | 18/14                    | Left DLPFC             | 10             | 110             | 1,000                  | 10              | Within 12 h after stimulation | Pictures of facial affect      | Significant effects in emotion recognition |

**Abbreviations:** rTMS, repetitive transcranial magnetic stimulation; IFG, inferior frontal gyrus; iTBS, intermittent theta burst stimulation; TULIA, test of upper limb apraxia; IPL, inferior parietal lobule; cTBS, continuous theta burst stimulation; DLPFC, dorsolateral prefrontal cortex.

\textsuperscript{a}Sham stimulation was performed with a sham coil system without a magnetic field in Walther et al\textsuperscript{23} and Wölwer et al\textsuperscript{24} studies. Otherwise, these studies\textsuperscript{23,24} used the same parameters among active and sham groups. “Significant effects in social perception” meant that stimulation enhanced the ability to assess the accuracy of performance of hand gestures.\textsuperscript{23} “Significant effects in emotion recognition” meant that stimulation enhanced the ability to identify facial emotion based on photographs or videos.\textsuperscript{24}

### Table 3. Social Cognitive Outcomes Eligible for the Systematic Review.

| Study           | Neuromodulation technique | Emotion recognition | Social perception | ToM | Attributional bias |
|-----------------|---------------------------|---------------------|-------------------|-----|--------------------|
| Rassovsky et al\textsuperscript{21} | tDCS                      | MSCEIT, EIT, EAT    | —                 | —   | TASIT              |
| Brennan et al\textsuperscript{25}  | tDCS                      | ERT                 | —                 | —   | —                  |
| Rassovsky et al\textsuperscript{22} | tDCS                      | MSCEIT, FEIT        | PONS              | TASIT | —                  |
| Walther et al\textsuperscript{23}  | rTMS                      | —                   | TULIA             | —   | —                  |
| Wölwer et al\textsuperscript{24}   | rTMS                      | Pictures of facial affect | —                | —   | —                  |

**Abbreviations:** ToM, theory of mind; tDCS, transcranial direct current stimulation; MSCEIT, Mayer–Salovey–Caruso emotional intelligence test; EIT, emotion identification test; EAT, empathic accuracy task; ERT, emotion recognition task; FEIT, facial emotion identification test; PONS, profile of nonverbal sensitivity; rTMS, repetitive transcranial magnetic stimulation; TULIA, test of upper limb apraxia.
Effects of rTMS. Two studies (one high-frequency rTMS study and one theta burst stimulation study) were included in the systematic review. Both studies targeted patients with schizophrenia.23,24 A single-session continuous theta burst stimulation over right IPL showed statistically significant effects on social perception, as assessed by the TULIA.23 Multi-session high-frequency rTMS over left DLPFC showed statistically significant effects on emotional recognition, as assessed by the pictures of facial affects.24

Discussion

To the best of our knowledge, this is the first systematic review to investigate the impact of tDCS and rTMS on social cognitive dysfunctions in psychiatric disorders. Specifically, 3 RCTs showed a significant effect of tDCS and rTMS targeting the left DLPFC on the emotion recognition domain (eg, identification of facial emotion based on photographs or videos) in patients with schizophrenia22,24 or depression.53 In addition, rTMS on the right IPL ameliorated social perception (eg, ability to assess the accuracy of performance of hand gestures) impairments of schizophrenia.23 These findings are clinically meaningful in that social cognition deficits greatly affect the functional outcomes in individuals with psychiatric disorders, especially schizophrenia and mood disorder.6-8,34 In this discussion below, we focus on emotional recognition and ToM, because the domains of social cognition are widely diverse.

The majority of studies (n = 4) used stimulation on the frontal areas, ie, the left DLPFC, which resulted in limited effects. The neural network of social cognition consists of the orbitofrontal cortex, medial prefrontal cortex, superior temporal sulcus, and amygdala, whose functional connectivity is decreased in most of the psychiatric disorders.35 Among them, the amygdala plays a key role in emotion recognition, while the prefrontal cortices are strongly associated with the ToM.37 On the other hand, the superior temporal sulcus is related to both domains of social cognition.38 These lines of evidence may provide a clue to the identification of novel stimulation sites, for example T3 or T4 of the international 10-20 electroencephalography system.53 Therefore, further scrutiny of stimulation sites is warranted to effectively alleviate social cognition disturbances of developmental disorders.

In conclusion, neuromodulation for social cognition deficits is a developing field, especially in terms of the effect of intervention and mechanism of action, which deserves further research.

Limitations

There is heterogeneity in the experimental design and stimulation protocols for the current review. For example, several variables, such as diagnosis, stimulation site, intensity, duration, and outcome measures may potentially affect the results. Moreover, multiple-session-offline stimulation protocols may be required to attain social cognitive improvement60 although almost all studies examined in this review used single-session-online stimulation protocols. Results from this systematic review of studies so far conducted may not provide conclusive evidence for the effectiveness of tDCS or rTMS on social cognition in psychiatric disorders. Further research is warranted to identify optimal parameters to maximize the cognitive benefits of tDCS and rTMS.

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Author Contributions
YY, TI, and TS planned the study. YY designed it and drafted the first manuscript. YY and TI independently searched and assessed the literature. TS approved the final list of included studies. TI, NH, and TS critically reviewed the draft and revised it. All authors made substantial contributions and approved the final manuscript.

Conflict of Interest Statement
The authors declared that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplemental Material
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ORCID iD
Yuji Yamada https://orcid.org/0000-0002-2169-1635

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