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Evaluation of a Modified High-Definition Electrode Montage for Transcranial Alternating Current Stimulation (tACS) of Pre-Central Areas

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ABSTRACT

Objective: To evaluate a modified electrode montage with respect to its effect on tACS-dependent modulation of corticospinal excitability and discomfort caused by neurosensory side effects accompanying stimulation.
Methods: In a double-blind cross-over design, the classical electrode montage for primary motor cortex (M1) stimulation (two patch electrodes over M1 and contralateral supraorbital area) was compared with an M1 centre-ring montage. Corticospinal excitability was evaluated before, during, immediately after and 15 minutes after tACS (10 min., 20 Hz vs. 30 s low-frequency transcranial random noise stimulation).
Results: Corticospinal excitability increased significantly during and immediately after tACS with the centre-ring montage. This was not the case with the classical montage or tRNS stimulation. Level of discomfort was rated on average lower with the centre-ring montage.
Conclusions: In comparison to the classic montage, the M1 centre-ring montage enables a more focal stimulation of the target area and, at the same time, significantly reduces neurosensory side effects, essential for placebo-controlled study designs.

Introduction

Transcranial alternating current stimulation (tACS) currently attracts increasing interest as a method to modulate intrinsic neural oscillations by externally applying weak alternating electrical fields [1] and its potential to analyse causal relationships between neural activity and behaviour [2]. However, it is well known that tACS of central to frontal areas is heavily impacted by neurosensory effects such as visual (phosphenes) or skin sensations (tingling, burning, pain) that are influenced by the stimulation frequency [3–5]. In particular phosphenes are most pronounced at frequencies in the beta range and increase with stimulation intensity [6,7], most likely due to expansion of the electrical field into the retina [6]. Besides causing discomfort, these side effects are critical since they hamper effective blinding of participants and hence impede placebo-control or crossover study designs. Computational modelling suggests that increasing the number of 'return' electrodes might reduce the occurrence of visual side-effects [6]. In this regard, a 4×1 high-density electrode montage, originally proposed for transcranial direct current stimulation [7], renders a possible solution to these inherent technical problems of tACS [8]. However, exact electrode placement assuring adequate distance between electrodes becomes more difficult, which bears the risk of an uneven distribution of the electrical current or shunting of current over the skin. We therefore evaluated a modification of the high-density montage consisting of one single circular ring electrode surrounding the central electrode overlaying the target area aiming at two main objectives.

Firstly, it was analysed whether an adequate penetration of the motor cortex can be achieved with the ring montage. Previous work has shown an online increase of corticospinal excitability during

Abbreviations: tACS, transcranial alternating current stimulation; tRNS, transcranial random noise stimulation; TMS, transcranial magnetic stimulation; rMT, resting motor threshold; MEP, motor evoked potential; FDI, first dorsal interosseus muscle.

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20 Hz tACS as evaluated with single-pulse transcranial magnetic stimulation (TMS) at rest [9–12]. This effect has been attributed to the acute modulation of the discharge rate of neural firing [13,14]. Therefore, we hypothesized a sufficient current flow through the motor cortex with the ring montage in case of significant tACS-induced modulation of corticospinal excitability.

Secondly, it was evaluated whether tolerability of the new montage, i.e. comparably reduced discomfort through accompanying somatosensory and visual side effects, is superior to the classical M1–contralateral supraorbital area (M1–SO) electrode formation.

Materials and methods

Ten (5 female, mean age in years 22.81 ± 2.76, range 20.3–30.2 years, all right-handed) participants volunteered in the experiment. None reported a history of medical, neurological or psychiatric diseases or any contraindications for non-invasive brain stimulation, as probed by a standardized questionnaire based on available safety recommendations [15,16]. All participants were naive to the experimental purpose and gave full written informed consent to participate in the experiment in accordance with the medical ethics committee of KU Leuven (protocol number S57359).

The influence of electrode montage on the tACS effect on motor cortical excitability and neurosensory side effects was tested in a double blind crossover design. Participants and study personnel involved in data acquisition and analysis were blind regarding the type of stimulation condition (20 Hz tACS versus placebo). Twenty Hz tACS with classical montage, 20 Hz tACS with ring montage, and random noise stimulation as control condition with either of the montages were tested in three separate sessions in pseudo-randomized order. To avoid potential carry-over effects, a minimum interval of 1 day between sessions was aimed for [17–20]. Within each session, the measurement of corticospinal excitability was performed immediately before (BASELINE), exactly 5 minutes after stimulation was switched on (ONLINE), immediately after (POST) and 15 minutes after stimulation cessation (POST15) (Fig. 1A). Participants evaluated their subjective level of neurosensory discomfort caused by tACS at the end of each session (Visual Analogue Scale, $VAS_{discomfort}$, extremes constituted of "I perceived nothing" and "I perceived the worst imaginable discomfort/pain") and level of fatigue at the beginning and end of each session ($VAS_{fatigue}$, extremes constituted of "absolutely not tired" and "maximally tired").

Transcranial alternating current stimulation

TACS was applied through conductive patch electrodes (NeuroConn, Ilmenau, Germany) in two different formations: For both, the (A) classical montage (Fig. 1B) and the (B) ring montage

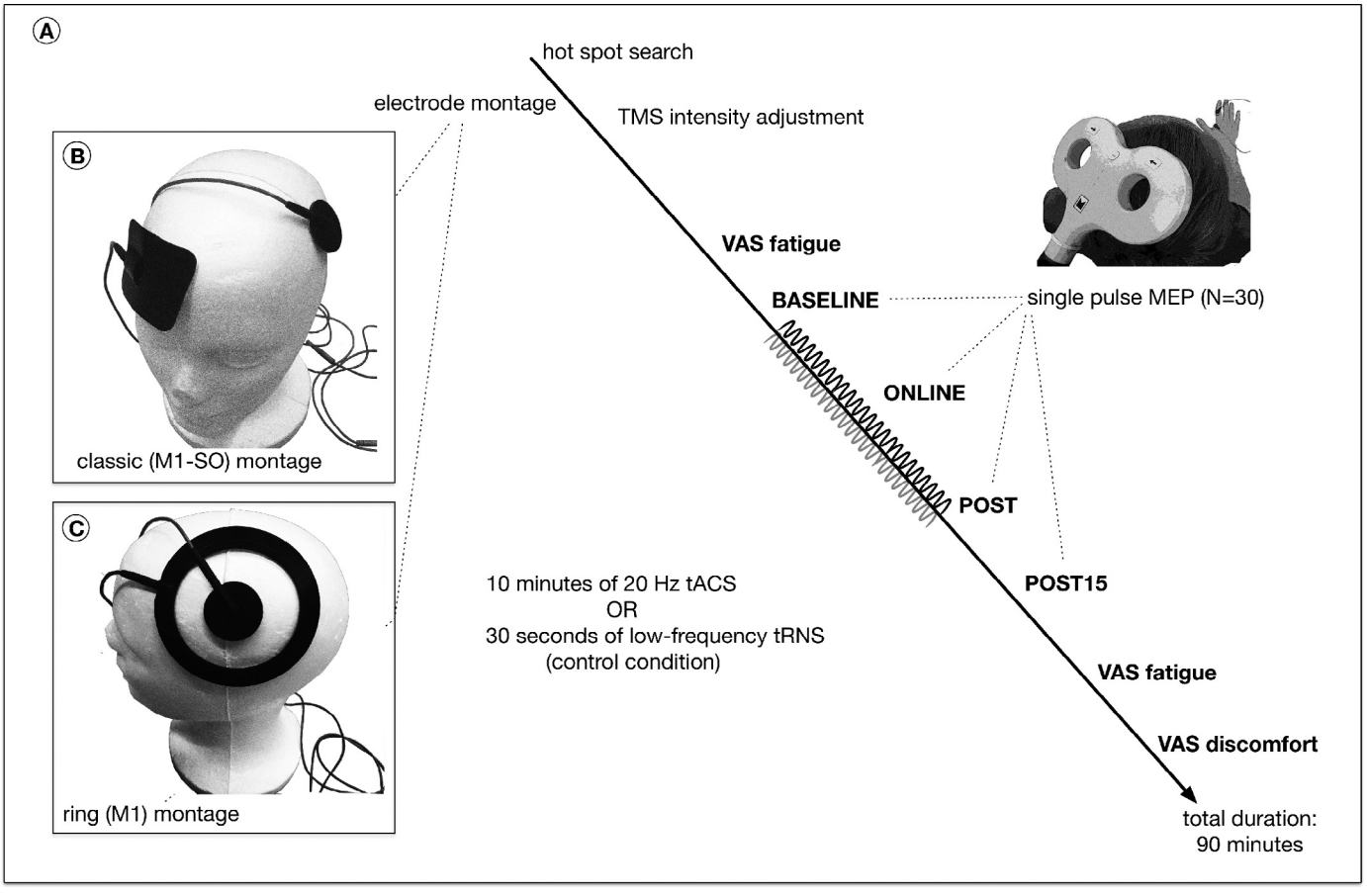

Figure 1. (A) Experimental time flow within in one session. Standard procedures were applied to retrieve the hot spot for the first dorsal interosseus muscle (FDI). TMS intensity was adjusted after tACS electrodes were fixed on the head with non-conductive elastic bands. 30 MEPs were collected before (BASELINE) tACS/tRNS onset, during, i.e. 5 minutes after tACS/tRNS onset (ONLINE), immediately after (POST) and 15 minutes after tACS cessation (POST15). Participants evaluated their subjective level of neurosensory discomfort caused by tACS at the end of each session (Visual Analogue Scale, $VAS_{discomfort}$) and level of fatigue at the beginning and end of each TMS session ($VAS_{fatigue}$). (B) Schematic of classic montage with target electrode (3.4 cm diameter, 9 cm^2) over the primary motor cortex, centred at the FDI hotspot, and the 'return' electrode (5 × 7 cm, 35 cm^2) overlaying the right supraorbital area. (C) Schematic of ring montage with a circular 'return' electrode (7.5 cm inner and 10 cm outer diameter, 34.5 cm^2) surrounding the target electrode (same as in the classic montage, 3.4 cm diameter, 9 cm^2). The distance between outer borders of the central and the surrounding electrode was 2.05 cm.